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NOTES ON ISOTELUS, ACROLICHAS, CALYMENE, AND ENCRINURUS

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The exact correlation of strata by means of fossils requires an equally exact discrimination of these fossils into species and varieties. Especially is this true of genera in which many of the species are closely related. In the genus *Calymene*, for instance, almost any Ordovician species has been called *C. senaria*, while almost any Niagaran species has been called *C. niagarensis*. Recently Raymond (Bull. Mus. Comp. Zoology, Harvard Univ., 60, 1, 1916, p. 27) has placed the Niagaran species on a better footing. In a similar manner, the various species in the Cincinnatian strata of Ohio, Indiana, and Kentucky need more exact discrimination. Very little has been published on the species of *Isotelus* in the Cincinnatian strata. Moreover, the published figure of *Encrinurus ornatus* was altogether insufficient for purposes of discrimination from closely similar forms found in other strata. The following pages are intended as a contribution to a more exact discrimination of some of the closely similar forms of the genera mentioned above.

Isotelus brachycephalus sp. nov.

Plates XIV, XIVA, and XV

Cephalon (plate XIV) 10.5 cm. in length along its median line, and 26.3 cm. in width at the genal angles; the ratio of the length to the width being four-tenths. The marginal border is depressed or concave for a width varying from 13 mm. anteriorly to nearly 20 mm. along the free cheeks. The facial suture is outlined distinctly both anteriorly and posteriorly to the palpebral lobes, and the position of these lobes is indicated, but the course of the suture along the margin of the palpebral lobes can

not be determined with certainty. Anteriorly the facial sutures are almost marginal, being only 0.5 mm. distant from the anterior margin of the cephalon. They almost meet the anterior margin of the cephalon, at points about 37 mm. on each side of its median line. The length of the genal spines is not known, but, judging from the width of their proximal ends, the tip of these spines must have extended at least as far as the posterior margin of the fourth segment of the thorax.

The length of the thorax (plates XIV and XIVA) along its median line is 12.5 cm.; and its width is about 25.3 cm. There are eight segments, as in other species of *Isotelus* in their adult state. The width of the axial lobe is 10 cm. The broad median groove along the proximal half of the pleural segments, and the diagonal ridge crossing their more distal parts, are as in other species of *Isotelus*.

The posterior end of the pygidium (plate XIVA) is not preserved, but its length is estimated at 13.8 cm., measuring from the posterior margin of the thorax; its width is 24.8 cm.; the ratio of the length to the width being about 55 per cent. Along the antero-lateral angles the surface inclines abruptly downward, forming a low ridge, posterior to which, proximally, there is a broad groove, similar to that along the proximal parts of the pleural segments of the thorax. The marginal part of the pygidium is inclined downward and is slightly concave, the width of this marginal part varying from 3.5 to nearly 4 cm.

The entire length of the specimen is 36.8 cm., the ratio of this length of the entire individual to the width of the pygidium being almost equal to the ratio of three to two; and the ratio of this length to that of the pygidium alone equals that of twenty-seven to ten. From this it is evident that the length of the entire individual falls short of equalling three times the length of the pygidium.

Locality and position. The large specimen of *Isotelus* described above occurred at the western end of the excavation for the conduit beneath the Huffman Conservancy dam, six miles northeast of the center of Dayton, at an elevation of 745 feet above sea, and 162 feet below the base of the Brassfield forma-

tion. The trilobite was lying on its back, and it remained attached to the upper half of the indurated clay layer in which it was imbedded. Five feet above the trilobite horizon was found a single specimen of *Columnaria vacua* Foerste. Since in the northwestern quarter of the Waynesville quadrangle the *Hebertella insculpta* layer, forming the base of the Liberty member of the Richmond formation, lies about 165 feet beneath the base of the Brassfield formation, the horizon at which the large *Isotelus* at the Huffman Conservancy dam was found must be either in the base of the Liberty member or near the top of the Waynesville member of the Richmond formation. The writer is indebted to Arthur E. Morgan, chief engineer of the Miami Conservancy District, for the privilege of studying this specimen.

At the bluff adjoining the southern end of the Huffman Conservancy dam the Brassfield limestone is underlain by the Elkhorn clay shale, 60 feet thick, and this in turn by the Whitewater member of the Richmond, but the line of contact of the Whitewater with the Elkhorn could not be determined on account of the muddy clay adhering to the rock as the result of continuous quarrying operations.

A second large specimen of *Isotelus*, apparently belonging to the same species as the Huffman Conservancy dam specimen was found by Dr. George M. Austin in the *Isotelus* clay layer in the upper or Blanchester division of the Waynesville member of the Richmond formation, at a locality about $2\frac{1}{2}$ miles northeast of Oregonia, in Warren County, Ohio. This locality is on Roaring Run, about three-quarters of a mile northwest of the Flat Fork school. The length of this specimen was 23.5 cm. The original was an impression in clay, the trilobite lying on its back, and of this impression Dr. Austin secured the plaster of Paris cast, here illustrated on plate XV. In all essentials this smaller specimen is similar to the larger specimen, described above. The ratio of the length of the head to its width is as five to ten. The ratio of the length of the pygidium to its width is 58 per cent. The basal part of the genal spine on the right side of the specimen is preserved, but its tip is gone, so that there is no means of determining its exact length. It probably

reached beyond the posterior margin of the third thoracic seg-
ment, possibly as far as the posterior margin of the fourth seg-
ment.   In this specimen it is not possible to determine how close
the anterior parts of the facial sutures are to the anterior margin
of the cephalon, since they are not clearly differentiated here.
The state of preservation of the thoracic segments and of the
pygidium is excellent, and this is the chief reason for presenting
here a figure of this smaller specimen.   In the collections at
Wilmington College, in Ohio, a cephalon occurs which has a
length, along its median parts, of 8.5 cm., and a width of 20
cm.   This specimen evidently came from the base of the Liberty
formation, since the slab contains also columns of *Glyptocrinus
richardsoni* Wetherby, which is characteristic of that horizon.

Remarks.   Both the Huffman Conservancy dam specimen
and the Roaring Run specimen are characterized by cephalons
and pygidia which are remarkably short compared with their
width.   This is true also of the Wilmington College specimen.

Only two species of *Isotelus* have been described from the
Richmond formation: *Isotelus maximus* Locke from the Liberty
member of the Richmond in Ohio, and *Isotelus iowensis* (Owen)
from the Maquoketa member in Iowa.

Isotelus iowensis is a much smaller species, 10 to 12 cm. long,
with much more elongate cephalons and pygidia, compared
with their width.

Isotelus maximus is founded on two specimens found in the
Liberty member of the Richmond formation a short distance
above the mouth of Treber's Run, three-quarters of a mile
southwest of Duncanville, and 8 miles southwest of Peebles,
Ohio.   Here the two types were found by Dr. John Locke in a
strongly rippled layer of limestone, the ripples varying from 2
to 3 feet in distance from each other, and the troughs varying
from 2 to 3 inches in depth.   Similar rippled layers of lime-
stone occur at higher elevations up the run.   Both of the type
specimens were figured by Dr. Locke (Geol. Surv. of Ohio, 1838,
pp. 247–249, figs. 8, 9; see also fig. 1 and 2 on plate XVII of
this publication), and they are mentioned again in his descrip-
tion of *Isotelus megistos* Locke (Amer. Jour. Sci., 42, 1842, p.
366, pl. 3, fig.).

The specimen described first by Locke consisted of a fragment of the reflexed margin or doublure of the posterior part of the pygidium; this fragment was 5 inches long and 1¾ inches wide, and it was marked by "veins," but its curvature was so small that it suggested "the end of an ellipse 22 inches long and 12 inches broad." The posterior termination of the axial lobe could be recognized. All of these features are represented in figure 8, accompanying Locke's original description of this species (see also fig. 1 on plate XVII of this publication), but other features are added so as to indicate the relative position of the fragment in the pygidium. Essentially, nothing is known about this type except that its posterior margin was of small curvature. So little of the pygidium is preserved that it is impossible to determine the ratio of the length of the latter to its width. As a type it is worthless.

The specimen described second by Dr. Locke (fig. 9 accompanying his original description; see also figure 2 on plate XVII herewith), consisted of an entire pygidium about 3½ inches in length, but this pygidium was enlarged by Dr. Locke to twice its natural size, and a thorax and cephalon, based on *Isotelus megalops* Green (Mon. Tril. N. Amer., 1832, p. 70, cast No. 25), was added, producing a drawing 21 inches in length. Only the pygidium of this drawing belongs to *Isotelus maximus*, and this pygidium is distinctly more elongate and more triangular than the pygidia of the Huffman Conservancy dam and Roaring Run specimens described above, the ratio of length to width of Locke's specimen being about 65 per cent.

Although the more perfect pygidium, found by Dr. Locke, was described and figured by him second, it is the only one of the two specimens sufficiently complete to serve as a basis for the identification of other specimens, the first specimen suggesting merely large size but no other specific characters. On this account figure 9 of Locke (fig. 2 on plate XVII of this publication) is chosen as representing the *type* of *Isotelus maximus;* figure 8 *may* belong to the same species as the Huffman Conservancy dam and Roaring Run specimens, described here, but there is no means of determining this with certainty.

Apparently there are two species of *Isotelus* present in the Liberty and Waynesville members of the Richmond of Ohio and adjacent states. One of these has more elongate cephalons and pygidia, and is represented by the pygidium used by Dr. Locke for his figure 9. For this species the name *Isotelus maximus* is retained. The second species, represented by the Huffman Conservancy dam and Roaring Run specimens, has relatively shorter cephalons and pygidia and is regarded as a distinct species for which the name *Isotelus brachycephalus* is proposed.

A large pygidium of *Isotelus* resembling in outline that of *Isotelus maximus* (fig. 9 of Locke), was found in the Stony Hollow, northwest of Clarksville, Ohio, by Prof. S. R. Williams of Miami University. Imbedded in the same slab is *Hebertella insculpta*, and it was found at the extreme top of the Waynesville member of the Richmond group. This pygidium is $5\frac{1}{2}$ inches long and 7 inches wide, thus indicating that *Isotelus maximus* actually attains as large a size as *Isotelus brachycephalus*, and is not confined to the smaller size used by Locke for his figure 9.

It is customary to refer *Isotelus megistos* Locke (Amer. Jour. Sci., 42, 1842, p. 366, pl. 3; see also plate XVI of this publication) to *Isotelus maximus* Locke. This is natural since Locke himself included the two type specimens of *Isotelus maximus* in his description of *Isotelus megistos*. However, the original description of *Isotelus megistos* begins with a description of a specimen found by Wm. Burnett on the hills at Cincinnati, and this is the specimen figured on the plate accompanying Locke's paper. The horizon at Cincinnati apparently was not in the Richmond but in the upper half of the Maysville formation, possibly in the, Corryville. Compared with *Isotelus brachycephalus* both the cephalon and the pygidia of *Isotelus megistos* are more elongate. The eyes are located nearer the posterior margin of the cephalon, and the anterior parts of the facial sutures are much more distant from the anterior margin of the cephalon. The space between the facial sutures, anterior to the eyes, is much more elongate. From this it seems evident that the specimen described by Locke from the Cincinnati hills belongs to a distinct species, for which the name *Isotelus megistos* might be retained.

Considering how abundant the fragments of large specimens of *Isotelus* are at various horizons in the Richmond formation it seems strange that no attempt has been made to illustrate them fully.   Our knowledge of *Isotelus maximus* is confined to the few notes and the meager illustrations presented by Locke in his original publication.   The numerous citations of *Isotelus maximus* from other authors concern chiefly closely similar, but probably not identical, Trenton forms.   The Cincinnati species described by Locke under *Isotelus megistos* also needs further elucidation.   It is hoped that the present publication of illustrations of *Isotelus brachycephalus*, and the accompanying observations on *Isotelus maximus* and *Isotelus megistos* will stimulate an interest in the large specimens of *Isotelus* occurring in Ordovician strata.

Accompanying his original description of *Isotelus maximus*, Locke published a figure of this species as though of an individual 21 inches in length.   His figure was based upon a pygidium of only half the size of that included in the figure, enlarged so as to correspond in size to a second pygidium of which he had only a fragment of the doublure.   In a similar manner Clarke published a figure of *Isotelus maximus*, from the Prosser limestone at Mentorville, Minnesota (Geol. Minnesota, 3, pt. 2, 1894, p. 706, plate) as though of an individual 17 inches in length. His figure was based on a fragment of a large glabella.   Both figures are based on estimates; both undoubtedly represented large specimens of *Isotelus;* but actual figures and measurements of large complete specimens are preferable, and an accumulation of such figures and measurements is necessary before the large forms of *Isotelus* can be discriminated successfully into species.

Both of the large specimens of *Isotelus brachycephalus*, here figured and described, were found lying on their back imbedded in the middle of an indurated clay layer.   In fact, all of the large specimens of *Isotelus* found by Dr. George M. Austin in place in the Richmond strata of Clinton and neighboring counties in southwestern Ohio, between ten and fifteen in number, were found imbedded in clay and lying on their back.   Evidently the specimens were covered by clay before decay dismembered the

pleural segments of the thorax and permitted the free cheeks to separate from the cranidium. Very few specimens that remained in their natural position escaped dismemberment during decay. Dr. Welch, now dead, but formerly also a resident of Wilmington, Ohio, found one of the few specimens ever seen imbedded in a natural position in the rocks, but the parts of his specimen were badly disarranged. These facts suggest a rapid deposition of the clay layers in which the large specimens of *Isotelus* were found.

In Cincinnatian areas thin layers of limestone, several inches thick, frequently are interbedded with somewhat thicker layers of clay, often a foot or more in thickness. The limestone layers often consist of more or less comminuted fragments of bryozoans, shells, and other organic remains, and are remarkably free of clay except in very moderate quantities. Apparently the waters that stirred up the organic fragments and removed the clays from the future limestone layers kept these clays more or less in suspension and later permitted their deposition when the violence of the motion of these waters had considerably diminished. In this manner considerable quantities of clay may have been deposited in relatively brief periods of time.

Little is known of sex differences among the trilobites. The presence of both broad and narrow forms of *Isotelus* in the Richmond strata of Ohio and Indiana suggests the possibility that the more elongate forms (*Isotelus maximus*) may be the males, and the broader forms (*Isotelus brachycephalus*) the females of the same species. Our present knowledge does not permit us to determine with any confidence whether the differences noted are connected with sexual differences or not.

ACROLICHAS

For the American species at present referred to the European genus *Amphilichas*, the generic term *Acrolichas* is proposed, on account of differences in the structure of the pygidia belonging to the American species. These pygidia have three pairs of ribs,

all with free tips, but only the first two pairs of ribs bear median grooves; moreover, the axial lobe narrows posteriorly to an acute point which reaches the notch between the free tips of the posterior pair of ribs. *Lichas cucullus* Meek and Worthen (Plate XVII, Figs. 4 A,B) is chosen as the genotype. In the Waynesville member of the Richmond formation, in Ohio, *Acrolichas* is represented by *Lichas harrisi* Miller, and a species with coarser pustules is present in the upper part of the Liberty member and the lower part of the Whitewater member of the Richmond.

Acrolichas (?) shideleri sp. nov.

Plate XVII, Figs. 3 A, B

Two fragments, both interpreted as right free cheeks of some Lichad. The general outline is falcate, but along the anterior part of the outer margin of both fragments the curvature is concave. Along its entire length, this outer margin is coarsely striated, the width of the striated border varying from 2 mm. near the posterior end of the free cheek to about 5 mm. along its concave curvature. Posteriorly, these striae are directed diagonally outward and backward. Along the concavely curved part, the striae bend up and down in an evenly concave manner. The remainder of the free cheek, in each specimen, is coarsely papillated, the apex of many of the papillae drooping diagonally downward in a sort of "tear-drop" manner. The inner margin of the tip of the free cheeks shows coarse striae, similar to those along the outer border, but diverging only slightly from this inner margin in direction; these striae can be seen only along the posterior part of the inner margin, within 4 mm. from the tip of the free cheek.

In one of these two fragments, the lower surface of the free cheek was freed from the matrix. This surface is coarsely striated with anastomosing lines, and at its proximal end it shows the inner limit of the test on the lower side of the free cheek. In removing the matrix, the anterior end of the free cheek, with its concave outer margin, was broken off.

Locality and position. At McDill Mill, about 6 miles north of Oxford, Ohio, on the main branch of Four Mile creek, half a mile northwest of the point where it is joined by East Fork. In the lower part of the Whitewater member of the Richmond formation, just above the *Gyroceras baeri* (Meek and Worthen) bed. Found by Prof. W. H. Shideler, in whose honor the species is named.

Remarks. The reference of these two free cheeks to *Acrolichas* is based chiefly upon their association in the same strata with cranidia undoubtedly belonging to *Acrolichas*, and the fact that these cranidia also bear coarse pustules. The pustules on these cranidia are of two sizes; the conspicuous ones are large and flat, and between these are others which are much smaller. A cranidium found in the basal part of the Saluda, on Hanna creek, one mile east of Liberty, Indiana, by Prof. W. H. Shideler, apparenty belongs to the same species as the cranidia associated with *Acrolichas* (?) *shideleri*.

A hypostoma of some species of *Acrolichas*, (plate XVIII, fig. 6) possibly *Acrolichas harrisi* (Miller) was found by Prof. Shideler just above the *Rhynchotrema dentatum* layer in the upper or Blanchester division of the Waynesville member of the Richmond, on Bull Run, less than a mile south of the railroad station at Oxford, Ohio. The anterior, broadly T-shaped half of the hypostoma is covered with numerous small pits. The lateral parts of the hypostoma are striated longitudinally with flexuous and more or less anastomosing lines. Along the posterior median parts, the pits are very minute and distant.

Calymene abbreviata Foerste

Plate XVIII, figs. 5 A, B

Calymcne abbreviata Foerste, Bull. Sci. Lab. Denison Univ., 16, 1910, p. 83, pl. 3, fig. 17. Jour. Cincinnati Soc. Nat. Hist., 21, 1914, p. 148, pl. I, figs. 14 A, B.

The type of *Calymene abbreviata* was found in the Cynthiana formation, one mile south of Rogers Gap, Kentucky. It is characterized by the straightened, truncated anterior margin of the glabella. The anterior two-fifths of the glabella tends to be

quadrangular, but posteriorly the dorsal furrows diverge widely. Along the anterior margin of the cranidium, the border equals almost a third of the length of the glabella.   Cranidia having the same structure occur in the Rogers Gap member of the Cynthiana formation, from Rogers Gap northward as far as Sadieville, Kentucky.

A similar cranidium (plate XVIII, fig. 5 A, B) was found also in the quarry east of Carnestown, on the Kentucky side of the Ohio river.   Here it occurred, associated with a single speci-ment of *Orthorhynchula linneyi*, about 10 feet above the railroad, and 56 feet below the base of the Fulton member, the latter containing *Triarthrus becki*.   Forty-two feet below the level of the railroad occur numerous specimens of *Dalmanella bassleri*, *Hallopora multitabulata*, and occasional specimens of *Stropho-mena vicina*, indicating the presence of typical Trenton strata, such as occur in central Kentucky.   Associated with the cra-nidium mentioned above, occurred a single pygidium, with five pairs of ribs, all of which, excepting those belonging to the last pair, have the distal halves bifurcated by median grooves, as in typical *Calymena senaria*.

Calymene sp. (Lorraine form)

Plate XVIII, fig. 1

At the Don Valley brick yards in the northeastern part of Toronto, in Canada, strata occur which are referred to the lower part of the Lorraine formation chiefly on account of the presence of *Trinucleus concentricus, Leptaena invenusta,* and *Catazyga headi,* all three associated in the same slabs.   Among other species occurring in these slabs are the following: *Climacograptus (Mesograptus) putillus, Iocrinus subcrassus, Plectambonites seri-ceus, Dalmanella* sp., *Zygospira modesta, Pholidops subtruncata, Pterinea demissa, Byssonychia radiata, Lyrodesma poststriatum, Modiolopsis* cf. *concentrica, Modiolopsis modiolaris, Cyrtolites ornatus, Lophospira bowdeni, Lophospira tropidophora, Sinuites cancellatus,* and a species of *Arthraria* 3 inches long.

With these fossils occurs a species of *Calymene* (Plate XVIII, fig. 1) which resembles *Calymene abbreviata* in the shortness of

its glabella and in the divergence of the dorsal furrows posteriorly, but differs in having a more rounded anterior margin on the glabella, in this respect agreeing with *Calymene meeki*, a species from the Maysville formation of Ohio, Indiana, and Kentucky. In *Calymene meeki* the ribs of the pygidium show only a trace of an impressed groove along their median line. The pygidium of the Don Valley specimens is unknown.

Calymene retrorsa minuens var. nov.

Plate XVIII, fig. 4

Compared with *Calymene meeki* Foerste (Bull. Sci. Lab. Denison Univ., 16, 1910, p. 84, pl. 3, fig. 18; also fig. 3 on plate XVIII accompanying this paper), *Calymene retrorsa* Foerste (Bull. Sci. Lab. Denison Univ., 16, 1910, p. 85, pl. 3, fig. 19; also fig. 2 on plate XVIII herewith) is characterized by rounded genal angles; a narrower, less triangular cephalon; and a shorter, less nasute anterior border, in front of the glabella. *Calymene meeki* is characteristic of the Maysville formation; and *Calymene retrorsa* is characteristic of the Waynesville member of the Richmond formation.

In the Whitewater member of the Richmond, both in Ohio and Indiana, a small form of *Calymene* occurs which has all of the characteristics of *Calymene retrorsa* but is constantly of smaller size. For this form the varietal name *minuens* is proposed. The specimen here figured (plate XVIII, fig. 4) was obtained at Richmond, Indiana, by John Misener.

In Ohio, *Calymene retrorsa minuens* is found in Clinton county, on a little branch entering Cowan creek, about a mile southeast of the entrance of the latter into Todd's Fork. Here the Liberty member of the Richmond formation is 43 feet thick. In its upper part, through a vertical range of 5 feet, *Pachydictya fenestelliformis* is fairly common, and a large form of *Streptelasma rusticum* is abundant. The even-bedded character of the Liberty member is continued into the lower part of the Whitewater member for a distance of 11 feet. Above this level the Whitewater strata become argillaceous and more or less nodular, and specimens of *Calymene retrorsa minuens* begins to make their appearance.

Calymene sp. (West Union form)

Plate XVIII, figs. 8 A, B

The type of *Calymene vogdesi* Foerste (Bull. Sci. Lab. Denison Univ., 2, 1887, p. 95, pl. 8, figs. 12, 16) is a large cranidium with a broad, massive border, separated from the anterior part of the glabella by a broad groove. The glabella is long, the dorsal furrows are not *strongly* convergent, and the anterior margin of the glabella has a broadly rounded outline. The accompanying pygidia have five pairs of ribs. All ribs, except those belonging to the last pair, are grooved for a short distance from the dorsal furrow, and for a longer distance from the distal end of the rib. Along the intermediate part of the ribs, the furrow is very faint or entirely obsolete. This species is characteristic of the Brassfield formation.

In the *Holophragma* zone at the top of the West Union formation at Hillsboro, Ohio, a much smaller species of *Calymene* occurs, (Ohio Jour. Sci., XIX, 1919, p. 402, pl. 18, fig. 6) about three-fifths as large as typical *Calymene vogdesi*. It has about the same form of cranidium, but the anterior half of the glabella is more quadrangular and is truncately rounded anteriorly; the anterior margin of the cranidium is relatively broad, but there is no broad groove separating this border from the anterior margin of the glabella, as in *Calymene vogdesi*.

In the *Trimerus* (formerly referred to *Homalonotus*) *delphinocephalus* zone, about 10 feet above the base of the West Union formation, at the quarry in the southeastern corner of West Union, Ohio, cranidia (figs. 8 A, B, on plate XVIII of this Bulletin) were found which closely resemble those from the *Holophragma* zone mentioned above. They differ chiefly in having a narrower anterior border, which bends more strongly upward, so that, from above, this border appears more narrow than its actual width. The accompanying pygidia show five pairs of ribs, the grooving of which can not be determined from the specimens at hand.

Calymene niagarensis Hall

Plate XVIII, figs. 12 A, B

Specimens from the Rochester shale of New York, furnished by the New York State Museum, through Dr. Ruedemann, have glabellae with a somewhat swollen frontal lobe, elevated rather abruptly above the frontal margin. The articulating margin along the anterior of the pygidium curves outward from the axial lobe and then backward to the posterior margin. When the axial lobe is placed in a horizontal position the posterior margin of pygidium appears rounded or slightly angular. The axial rings are transverse, about 7 in number, leaving only a very short posterior undifferentiated end.

Calymene breviceps Raymond

Plate XVIII, fig. 7

Calymene breviceps Raymond, Bull. Mus. Comp. Zool. Harvard Univ., 60, 1916, p. 27, pl. 3, fig. 11.

Specimens of the *Calymene* which is common in the Waldron shale at Newson, Tennessee, compared with typical *Calymene niagarensis*, have a somewhat flatter frontal lobe on the glabella, and this frontal lobe rises less above the anterior margin of the cranidium. The axial lobe of the pygidium has more convergent sides; the axial rings are curved, especially the anterior ring. When the axial lobe is placed in a horizontal position, the posterior margin of the pygidium is less curved and frequently has an almost transverse outline.

Calymene cedarvillensis sp. nov.

Plate XVIII, figs. 11 A, B, C

In the Cedarville dolomite, in the quarry at Cedarville, Ohio, a large species of *Calymene* is found, equalling *Calymene vogdesi* in size. The only complete specimen found, more or less distorted by pressure along its right side and along its anterior

margin, originally must have been nearly 95 mm. in length. The glabella has about the same structure as the glabella of the other Silurian species here described; it is relatively long, the anterior part tends to be quadrangular, and the dorsal furrows do not diverge strongly posteriorly.   The chief difference from *Calymene vogdesi* consists in the narrower anterior border which is not separated from the anterior part of the glabella by a groove distinct from the general curvature of the border.   Compared with *Calymene celebra* Raymond (Bull. Mus. Comp. Zool. Harvard Univ., 60, 1916, p. 28, pl. 3, figs. 9, 10) its anterior border is considerably wider.   Of the pygidium not much is known, but the shallow groove along the top of the ribs appears nearer the posterior margin of these ribs, at least along their distal half.

All of the Trenton and Cincinnatian species of *Calymene* in American strata known to the present writer have the abbreviated form of glabella, with the strongly divergent dorsal furrows.   All of the Medinan and Niagaran species have the more elongate form of glabella, with the more moderately divergent dorsal furrows.   The Trenton species include *Calymene senaria* Conrad, and *Calymene abbreviata* Foerste.   The Cincinnatian species include *Calymene granulosa* Foerste, *C. meeki* Foerste, *C. retrorsa* and variety *minuens* Foerste, *C. fayettensis* Slocom, and *C. gracilis* Slocom.   *Calymene callicephala* Green may have been founded on a poorly preserved erratic specimen of *Calymene senaria*.   The Medinan species include *Calymene vogdesi* Foerste, and the Niagaran species include *Calymene niagarensis* Hall, *C. breviceps* Raymond, *C. celebra* Raymond, and *C. cedarvillensis* Foerste.

Encrinurus ornatus Hall and Whitfield

Plate XVIII, figs. 9 A, B

Encrinurus ornatus Hall and Whitfield, Pal. Ohio, 2, 1875, p. 154, pl. 6, fig. 16.

The type of *Encrinurus ornatus* was found in the Cedarville dolomite at Cedarville, Ohio.   It is doubtful whether this species occurs at any other horizon than in the Cedarville dolomite, although closely similar forms occur at other horizons.   This species is found in the Cedarville dolomite not only at Cedar-

ville but also at the Moody quarry, in the southeastern part of Wilmington, Ohio, from which specimens occur in the collection of Dr. George M. Austin. The pygidium, in the best preserved interior cast found in this collection, figured herewith, has 7 pairs of ribs, of which the last pair is very short and is indicated chiefly by the nodular elevation of part of this rib. A cast of the exterior of another specimen suggests the possibility of an eighth pair of ribs, but this is doubtful. The chief characteristic of the species, as far as known, is found in the curvature of the ribs. The axial lobe is almost straight from front to rear. From this lobe all of the anterior ribs diverge strongly, and the backward curvature of their distal halves is more moderate than in any other Silurian species. The posterior termination of the pygidium of this species is unknown.

In *Encrinurus reflexus* Raymond (Bull. Mus. Comp. Zool., 60, 1916, p. 25, pl. 3, figs. 7, 8) from the Niagaran at Wauwatosa, Wisconsin, there are 8 pairs of ribs, and these are deflected more strongly toward the rear.

Encrinurus hillsboroensis sp. nov.

Encrinurus cf. *ornatus*, Ohio Jour. Sci., 1919, p. 391, pl. 18, figs. 2 A-C.

In the *Holophragma* zone, at the top of the West Union formation, at Hillsboro, Ohio, fragments of a species of *Encrinurus* occur which differ from either *Encrinurus ornatus*, or *Encrinurus reflexus* in the strong posterior reflexion of the distal parts of the ribs on the pygidium. There are 8 pairs of ribs and the pygidium terminates posteriorly in an acute spinose end. It is probable that a similar termination would be found also on the pygidia of other species if these parts were preserved.

In *Encrinurus thresheri* Foerste (Bull. Sci. Lab. Denison Univ., 2, 1887, p. 101, pl. 8, fig. 26; also pl. XVIII, fig. 10 of present issue) the ribs curve strongly backward as in *Encrinurus hillsboroensis*, but there are only 6 pairs of distinctly defined ribs, with a doubtful seventh pair parallel to the posterior end of the axial lobe. The type apparently is a cast of the lower surface of the pygidium, which accounts for the apparent narrowness of the ribs.

ADDITIONAL NOTES ON BRASSFIELD ECHINODERMATA

Since the publication of the article on the echinodermata of the Brassfield Formation, in the earlier part of this volume, Mr. Frank Springer, the eminent American authority on Crinoidea, has kindly offered the following notes on several of the specimens there figured.

The broad, flat calyx, represented by figures 2 A, B, C, and D on plate VI, belongs to the *Rhodocrinidae*, and may be similar to the form described by Weller, from the Racine of the Chicago area, as *Archaeocrinus depressus*. Hitherto we have supposed this genus to be purely Trenton and Chazyan, but the Racine and Brassfield forms appear to be close to it.

The specimen retaining both calyx and arms, obtained at the Centerville quarry, and forming figure 3 on plate III, is of the type *Patelliocrinus* Angelin, one of the rare Gotland forms, but the preservation of the Centerville specimen is tantalizing, and one does not feel sure of the structure.

The fragments of calyx and arms forming figures 4 A, B, on plate III, also found at the Centerville quarry, apparently belong to the *Flexibilia*, and very probably is *Pycnosaccus*, as far as can be determined in the absence of an entire calyx.

The problematical specimen described on page 28 as *Stereoaster squamosus* forms the genotype of *Stereoaster*, the latter being a new generic term, a fact not indicated in the text at the time of its original publication.

PLATES XIV AND XIV A

Isotelus brachycephalus sp. nov.; type.   An entire individual, figured in two parts, reduced in size.   The cephalon and the five anterior segments of the thorax are shown on plate XIV; the pygidium and the three posterior segments of the thorax are shown on plate XIV A.   The former presence of a genal spine is seen on the left side of the cephalon.   The length of this spine is unknown.   Parts of the reflexed lower margins of the free cheeks and of the pygidium are seen on the left side of the specimen.   Found in the base of the Liberty or the top of the Waynesville member of the Richmond, at the Huffman Conservancy dam, 6 miles northeast of the center of Dayton, Ohio.   Loaned by Arthur E. Morgan, Chief Engineer.
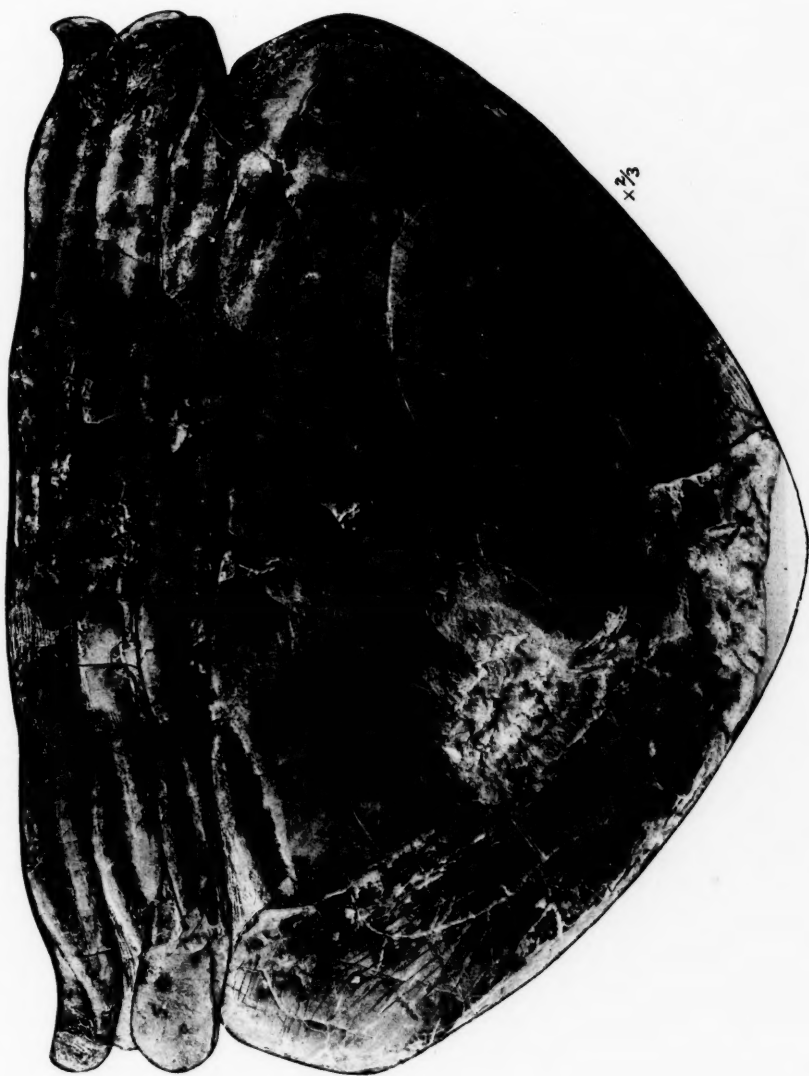
PLATE XIV

× 2/3

FOERSTE: ORDOVICIAN TRILOBITES

PLATE XIV A

× 2/3

FOERSTE: ORDOVICIAN TRILOBITES

PLATE XV

× 3/4
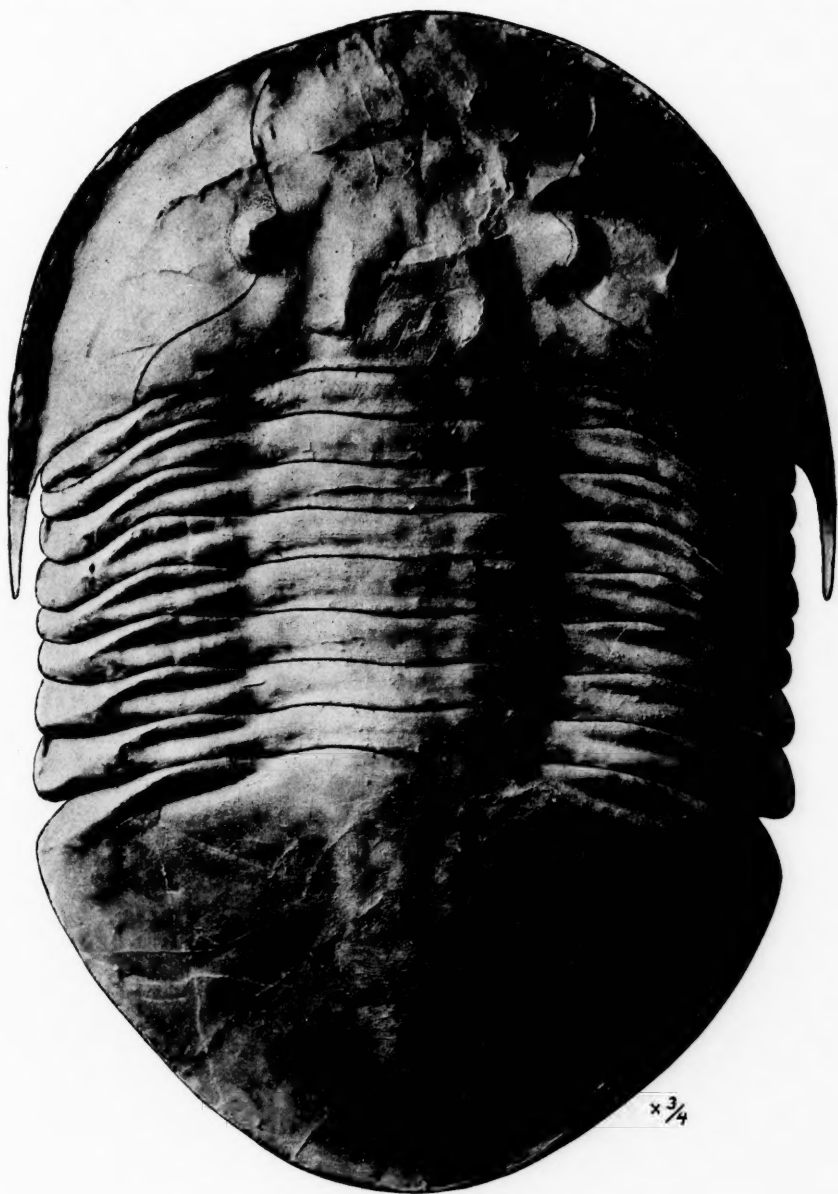
FOERSTE: ORDOVICIAN TRILOBITES

PLATE XVI

Isotelus megistos Locke; type specimen, described and figured in the American Journal of Science, vol. 42, in 1842; p. 366; pl. 3.   Found by Wm. Burnett on the hills at Cincinnati, Ohio, presumably in the upper part of the Maysville formation.

$\times \frac{3}{4}$
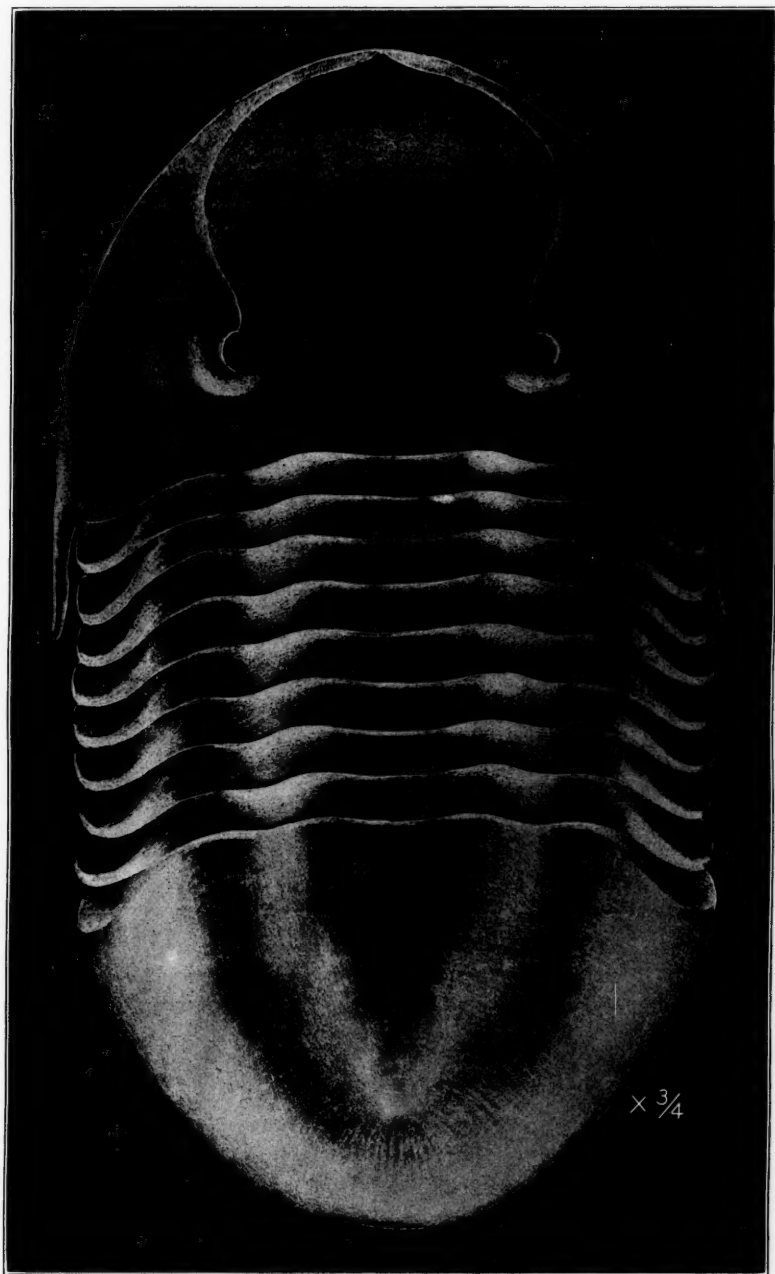
FOERSTE: ORDOVICIAN TRILOBITES

PLATE XVII

Fig. 1. Isotelus maximus Locke; one of the types figured by him in Geol. Surv. Ohio, 1838, pp. 247–249, plates 8 and 9. As the first published figure, this should be the type, but of this entire figure only that part was based on an actual specimen which is included in the marginal part of the pygidium, where the lower, reflexed doublure is shown by the removal of the upper part of the pygidium. This part is not regarded as sufficient to determine the outline of the pygidium. All of the remainder of the drawing was added to "place" the fragment in its proper surroundings in the pygidium. Found in the Liberty member of the Richmond, on Treber Run, 8 miles southwest of Peebles, Ohio.

Fig. 2. Isotelus maximus Locke; the second one of the types figured by Locke, as figure 9, found at the same locality and horizon as the preceding specimen. Copied from the enormous figure, 21 inches long, presented by Locke. This figure was based on a single pygidium, much smaller than the figure, the outline being based on the entire pygidium at hand and the size being enlarged so as to conform with the imagined size of the individual of which figure 8 illustrates only a fragment. Probably two species are represented by figures 8 and 9 of Locke. Of these, figure 9 is the only one including enough of an individual to make possible the identification of the type. In the opinion of the writer, either Locke's name, *maximus*, should be dropped or the name should be attached to the specimen represented by figure 9, which there is some chance of identifying, in the entire absence of Locke's types.

Fig. 3. Acrolichas (?) shideleri sp. nov. A, upper surface of a fragment regarded as a free cheek. B, under surface of a second, similar free cheek. Found in the Whitewater member of the Richmond, at McDill's Mill, 9 miles north of Oxford, by Prof. W. H. Shideler.

Fig. 4. Acrolichas cucullus ottawaensis var. nov. A, cranidium; B, pygidium. From the Trenton at Hull, opposite Ottawa, Canada. Collected by J. E. Narraway. Differing from the type chiefly in the rounded free tips of the ribs on the pygidium.

$\times \frac{2}{3}$

1

$\times \frac{7}{6}$

4 A

$\times 1.3$

$\times \frac{7}{8}$

2

4 B

$\times 2$

3 A

$\times 2$

3 B
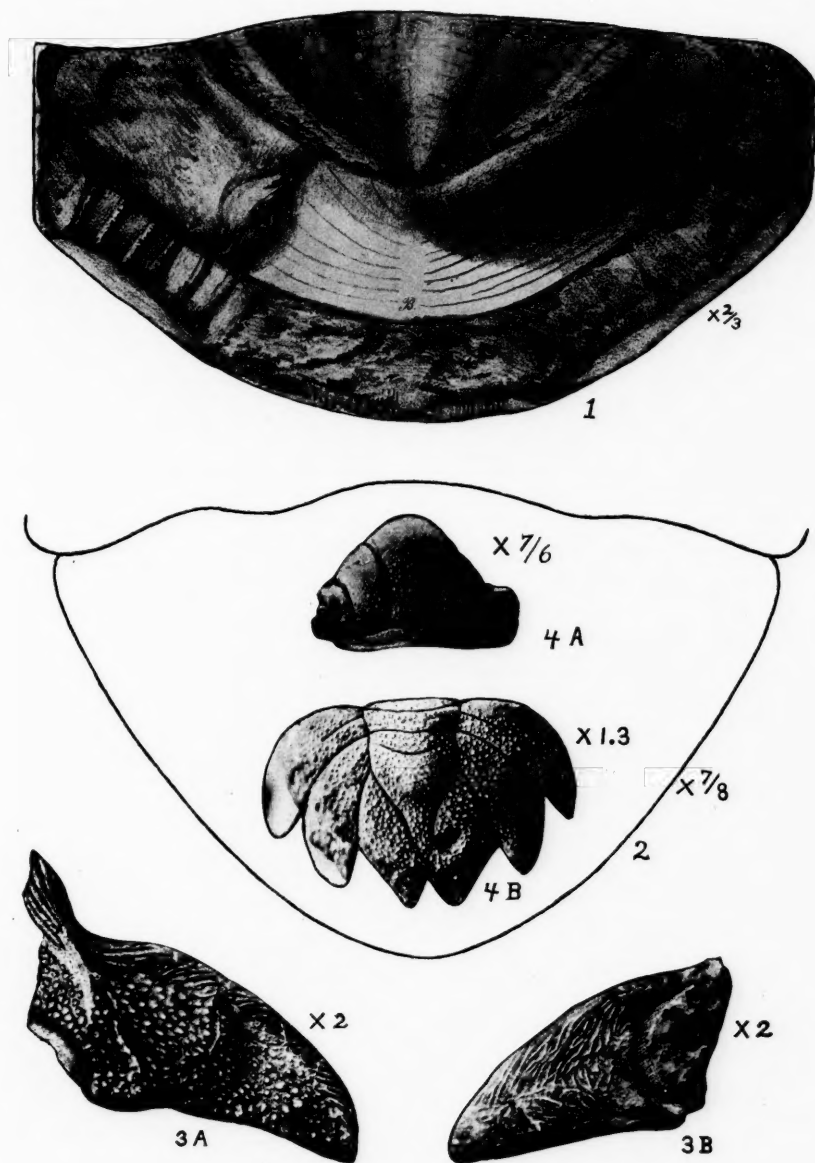
FOERSTE: ORDOVICIAN TRILOBITES

PLATE XVIII

Fig. 1. Calymene sp. (Lorraine form). Enrolled individual from Lorraine formation at Don Valley brickyards at Toronto, Canada.

Fig. 2. Calymene retrorsa Foerste. Lateral view of type; see Bull. Sci. Lab. Denison Univ., 16, 1910, p. 85, pl. 3, fig. 19. From middle or Clarksville division of Waynesville member of Richmond formation, on Silver Creek, east of Dunlapsville, Indiana.

Fig. 3. Calymene meeki Foerste. Lateral view of type; see Bull. Sci. Lab. Denison Univ., 16, 1910, p. 84, pl. 3, fig. 18. From Fairmount member of Maysville formation, at Cincinnati, Ohio.

Fig. 4. Calymene retrorsa minuens Foerste. Enrolled specimen, from Whitewater member, at Richmond, Indiana, collected by John Misener.

Fig. 5. Calymene abbreviata Foerste. A, cranidium; B, pygidium, with posterior part preserved. From Cynthiana formation at quarry east of Ivor, Kentucky.

Fig. 6. Acrolichas harrisi (Miller) (?). Hypostoma; found in Blanchester division of Waynesville member of Richmond formation, on Bull Run, southwest of Oxford, Ohio, by Prof. W. H. Shideler.

Fig. 7. Calymene breviceps Raymond; the posterior part of the occipital ring is broken off. Glabella. From Waldron shale at Newsom, Tennessee.

Fig. 8. Calymene sp. (West Union form). A, cranidium; B, pygidium. From the *Trimerus delphinocephalus* zone, ten feet above the base of the Bisher member of the West Union formation.

Fig. 9. Encrinurus ornatus Hall and Whitfield. A, pygidium, with the posterior tip missing; B, lateral view of same. From the Cedarville dolomite at the long abandoned quarry southeast of Wilmington, Ohio, west of the county infirmary.

Fig. 10. Encrinurus thresheri Foerste. Pygidium, with the posterior tip not clearly exposed, and with the anterior margin of the axial lobe missing; both restored. Type; see Bull. Sci. Lab. Denison Univ., 2, 1887, p. 101, pl. 8, fig. 26. From the Brassfield formation, at Dayton, Ohio.

Fig. 11. Calymene cedarvillensis Foerste. A, entire individual with right side and anterior margin distorted by crushing; B, part of cranidium; C, fragment of another cranidium. From the Cedarville dolomite at Cedarville, Ohio.

Fig. 12. Calymene niagarensis Hall. A, cephalon of enrolled specimen; B, lateral view of extended specimen. From the Rochester shale of New York, loaned from the New York State Museum, at Albany, through the courtesy of Dr. Rudolph Ruedemann.
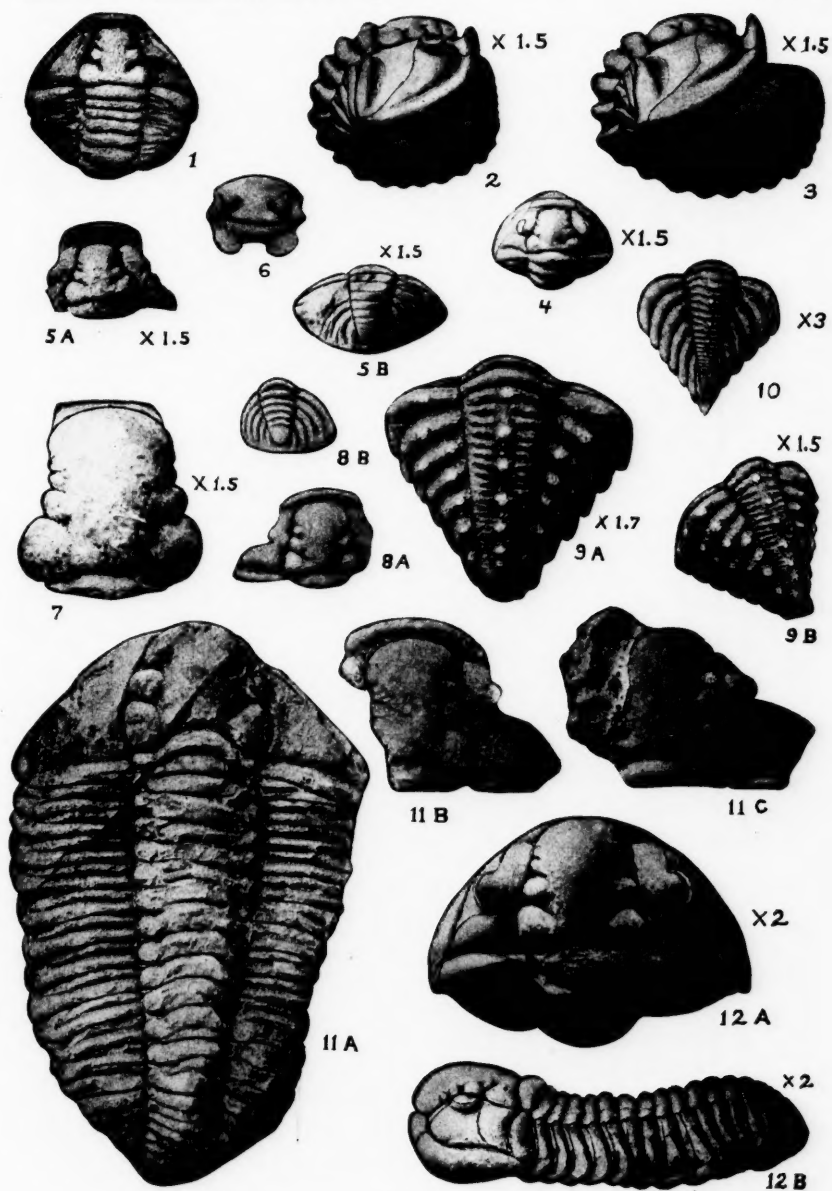
FOERSTE: ORDOVICIAN AND SILURIAN TRILOBITES

SOME SUGGESTED EXPERIMENTS FOR THE GRAPHIC RECORDING OF SPEECH VIBRATIONS

ROBERT JAMES KELLOGG

In an attempt to recast the science of phonetics on the basis of connected speech flow,[1] I have found it necessary to critically compare the results obtained by different methods of graphically recording speech vibrations. Out of this comparison a number of suggestions have emerged (1) for further perfecting certain existing types of apparatus, (2) for the application of apparatus already perfected to special linguistic problems, and (3) for the development of new types of apparatus in which the "light-lever" (or shifting ray of light responding to sound vibrations) partly or wholly replaces the physically vibrating parts.

These suggestions are presented herewith in the hope that they may be of interest and help to other investigators, and also that, if a larger number can cooperate in working them out, the practical and mechanical difficulties involved may be the sooner solved and the apparatus based on these principles devised and perfected.

I. THE PERFECTING OF EXISTING TYPES OF APPARATUS

It cannot be too strongly insisted that the mechanical perfection of diverse types is necessary if the problems of experimental phonetics are to be fully solved. Every type of sound recording apparatus distorts the sound curves in its own special way, suppressing, damping, modifying or adding specific vibrational elements. Even in the perfected apparatus this distortion may either require complicated correction of results (as in the phonodeik), or it may not be fully determinable from the unaided standpoint of the apparatus in question (as in the case

[1] Proc. Mod. Lang. Assoc., 1915, p. xxix, title 46: About face in fonetics.

of the manometric flame). But the results of diverse types of apparatus check and interpret each other. Thus in the case of the two types just mentioned, the phonodeik[2] gives legible sinusoidal records of even the minutest elements and phases of vibration, showing distinctive curves even of voiceless consonants and whisper sound,[3] but its records require varied and complicated corrections of horn and diaphragm effects.[4] The manometric flame as developed by Nichols and Merritt[5] is non-sinusoidal in its record and therefore hard to interpret, but it is apparently freer than any other apparatus from special mufflings and reinforcements. It is equally able to show the highest and minutest vibrational elements and phases.[6] Apparently therefore these two types of apparatus are complementary, each approaching perfection where the other is most defective.

Furthermore, it is impossible to forecast either the kind or value of results obtainable with any type of apparatus until it is perfected and its results thoroughly tested out. Thus, the phonograph and gramophone are merely perfected forms of Scott's crude phonautograph, which, though it has failed thus far to produce the visible graphic record originally sought, produces in these perfected forms practically perfect results in a new and unforeseen direction. Nichols and Merritt's manometric flame apparatus shows that Koenig's manometric figures consisted of partly overlapping images, which effectively concealed all minor phases of vibration, but that with a vibrating flame of high actinic power and high speed of the recording film, these figures are resolved and the minutest phases and shades of vibration clearly recorded. The phonodeik, with its marvellous sensitiveness to the minutest and most rapid vibratory movements, shows an equally marked advance over the cruder instruments of the same type developed by Blake, Argollot and Chavanon, Lebedeff, and Somojloff. Thus the three types

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[2] Miller, Science of Musical Sounds. New York, 1916.
[3] Ibid., figs. 170, 171, 172, 184; Phys. Rev., xxviii, 151 ff.
[4] Ibid., ch. V.
[5] Phys. Rev., i, 166–176, and vii, 93–101.
[6] See illustrations under the second article cited in note 5.

of apparatus (phonograph, phonodeik and manometric flame) which have been brought nearest to mechanical perfection, have all been developed out of exceedingly defective and seemingly unpromising types. It is therefore precarious to reject any type of apparatus on a-priori grounds, and surely worth while to study the problem of perfecting existing types of apparatus and devising new ones.

Enlargement of phonographic and gramophonic records. It is highly probable both on practical and theoretic grounds that the direct phonautograph type cannot be perfected to produce accurate sound curves large enough for direct reading. This appears both from the negative results attending long years of efforts and experiments directed to improving the phonautograph,[7] and from the fact that the degree of magnification, the inertia, length and flexibility of levers, and the amplitude of vibration demanded at the recording point are so great that the physical mechanism cannot conform to the rapid and complexly changing phases of speech vibration, and also necessarily introduces interfering vibrational elements of its own. But in the form of the phonograph and gramophone, the phonautograph has been brought to approximate mechanical perfection for the production of audible records, and the phonograph and gramophone grooves are therefore approximately perfect physical records of speech vibrations on a microscopic scale. Various means of enlargement have been tried in the effort to render the sound grooves legible.

Direct magnification[8] of the sound groove has thus far proved unsatisfactory for the phonograph and impossible for the gramophone. In the phonograph groove the sinusoidal element is perpendicular to the surface and therefore in the line of sight, and hence disappears both in direct microscopic observation by the eye and in microphotographic enlargement. The gramophone groove is indeed sinusoidal in the plane of the record, but the length of the sinusoids is so great in comparison with their

[7] Scripture, Elements of Experimental Phonetics. New York, 1902, pp. 17–24.
[8] Cf. Marichelle, La parole d'après le tracé du phonographe. Paris, 1897. See also Boeke in Pflueger's Archiv, 1891, p. 297.

amplitude that they are wholly illegible on any scale of enlargement. In other words, the difficulty rests for both instruments in the fact that the record is not made for visible but only for audible purposes. The remedy obviously lies in constructing phonograph and gramophone records for the express purpose of microscopic enlargement without regard to their fitness for audible reproduction (though a synchronous audible record could also be made for comparison if desired).

In the case of the phonograph, a micro-legible record could be made by using a wedge-shaped cutting sapphire (that is, one with two straight cutting edges meeting in a point), thus making the depth and width of the groove proportional and the edges true sinusoids of the sound vibrations recorded, and as such capable of direct microscopic enlargement and photographic reproduction and interpretation. Whether it could be made more easily legible and photographable by a surface coloring of the wax, could be determined by trial.

In the case of the gramophone, a micro-legible record could easily be made by sufficiently reducing the speed of the recording disk, thus foreshortening the vibrational curves to legible sinusoids. Such a record ought to be easily magnifiable sufficiently to show the minutest phases of vowel and consonant vibrations.

The unsatisfactory results hitherto attending microscopic enlargement of the sound groove led to various efforts at indirect enlargement, either by physical levers (as by Scripture,[9] Muenzinger[10] and others), or by physical and light-levers combined (as by Hermann,[11] Rosset[12] and others).

Scripture apparently carried the simple lever apparatus to the limit of its possibilities. He himself adjudges it inadequate and believes that "the future of the method lies in the develop-

[9] Elements of Experimental Phonetics, ch. IV, and Study of speech curves, Washington, 1906, ch. II.

[10] Bull. of Univ. of Texas, no. 24, April, 1915.

[11] See Elements of Experimental Phonetics, p. 38 ff, with the references there given.

[12] Recherches expérimentales pour l'inscription de la voix parlée. Paris, 1911.

ment of a compound lever."[13] He believes this inadequacy is due to the low degree of magnification obtainable (125 to 300 times). But a comparison of his results with those of Hermann, Rosset, Marichelle and Miller, shows that the failure of Scripture's apparatus to record consonantal and overtone vibrations is due to its low limit of sensitiveness and not to its low degree of magnification. Thus Marichelle shows the occlusive and explosive phases of voiceless consonants with a magnification of less than thirty diameters.[14] Miller's record of *Lowell Institute* as recorded in his Science of Musical Sounds[15] has a magnification only a little greater than that given by Scripture's apparatus, but it plainly shows the vibrations of even the occluded phases of *s* and *t*.

Muenzinger's compound lever apparatus neutralizes the weight of all levers through counterbalancing, and practically eliminates play and friction of bearings and joints by point or V-bearings. His first results do not exceed those obtained with Scripture's simple lever apparatus. Muenzinger's apparatus ought to be further developed and perfected in order to determine its full possibilities. Apparently any further progress in physical lever magnification of the sound groove must follow the lines that he has laid down. The future of the method must lie, not in seeking greater magnification as Scripture supposed, but in seeking greater sensitiveness, perhaps with lower magnification if that is necessary to secure it. The absorption of minute vibrational phases (due in Scripture's apparatus to play of bearings, infinitesimal bending of levers, and friction of the recording stylus) must be eliminated. Muenzinger's V-bearings will probably solve the first difficulty. The bending can perhaps be eliminated by using very light levers with delicate trussing or wire bracing, which are kept at a fixed temperature; the method probably cannot be perfected unless such rigid and delicate levers can be obtained. For the recording surface some

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[13] Study of Speech Curves, p. 26.
[14] La parole d'après le tracé du phonographe, figs. 83–86, p. 80.
[15] Figure 184, p. 254.

substance or surfacing approaching absolute smoothness must be sought.

Decidedly better results have been obtained by the combination of physical levers with light-levers. Hermann's work on this line (cited above) is well known. It is worth while, however, to call especial attention to Rosset's apparatus. A tiny concave mirror attached to the reproducing stylus of the phonograph reflects a beam of light to the recording screen, thus giving synchronous graphic and auditory records of the sound waves, the latter record testing and interpreting the former, and enabling him to perfect his apparatus. Fuller details of his method are given in his *Recherches expérimentales*, cited above. For want of adequate funds, his experiments were confined to working out the principle. With a lateral magnification of 250 times, he secured distinctive records not only of vowels, voiced consonants and spirants, but also of explosive *t*, of on and off glides in connected speech, and of the gradually changing form of the so-called simple vowels. His apparatus is probably capable of being brought to an extreme degree of delicacy and perfection, and the principle he uses may be capable of other applications. It would be well if some of our American laboratories could help in this development.

Sinusoidal manometric flame records. One other type of recording apparatus probably capable of being more fully perfected is the sinusoidal manometric flame record of J. G. Brown.[16] The direct non-sinusoidal form of the manometric flame has been approximately perfected by Nichols and Merritt, as noted above. Brown succeeded in obtaining a sinusoidal record by turning the exit tube of the manometric capsule on a downward slant, thus obtaining a curved flame with its outer portion curving upward and describing up and down harmonic motions with the variations of vibratory pressure in the manometric capsule. By using a clear actinic flame good photographic records of the flame sinusoids were obtained, as shown in illustrations in the article just cited. By using a smoky flame a sinusoidal record

[16] Phys. Rev., xxxiii, 442–446.

was deposited in soot on a revolving tambour. But the soot record is not wholly satisfactory because different portions of the flame deposit separate superposed records not wholly agreeing in form, as only the lower edge of the flame gives a true sinusoid. So far as published, Brown's apparatus was applied only to a few simple vowel sounds and its power of recording finer and higher speech sounds remains to be tested. But the extreme sensitiveness of the manometric flame as demonstrated by Nichols and Merritt, makes it probable that his apparatus could be developed and used along this line. It would therefore be of the utmost importance if this method could be so developed as to eliminate the superposed soot figures and give a single clear sinusoidal line. Perhaps this could be effected by using a generally clear flame in which a single tiny soot-producing source is introduced, and from which a fine line of soot would continuously pass to the recording tambour. If the method can be thus perfected, it would give a cheap, efficient and manageable way of producing clear and legible records of connected speech. How important this would be will appear plainly if we reflect that even our best equipped and endowed laboratories find serious mechanical and financial difficulties in making extensive records of connected sentences and words. To be legible the sinusoids must not be foreshortened, and when this condition is fulfilled, the record of even a single syllable becomes several feet long, complete words and sentences correspondingly longer, while a discourse may be measured by the mile. The mechanical difficulty and expense of producing photographic records on this scale is prohibitive. Hence the importance of developing a cheap and efficient means of producing extensive permanent records of connected speech. It would seem to be worth while for different laboratories to coöperate in experiments directed to this end.

II. APPLICATION TO SPECIFIC PROBLEMS

As to the application of perfected types of apparatus to specific linguistic problems, the chief need is undoubtedly a more extensive and intensive study of the phenomena of colloquial speech

—not merely of intoned vowels or selected syllables or formally enunciated phonographic records, but of actual spoken language in the setting of actual life. If, for instance, the phonodeik, either alone or in conjunction with the manometric flame, could be used to make as careful a study of the spoken language of many different persons, as it was used to make of intoned vowels,[17] it would likely solve many important problems. Note further how many types of apparatus have been barely developed and demonstrated, but for lack of funds never applied to the solution of urgent phonetic problems. Cases in point are the manometric apparatus of Nichols and Merritt and of J. G. Brown, Muenzinger's compound lever apparatus and Rosset's synchronous recording and reproducing apparatus, all of which were noted above. When we consider that language is the vehicle of all of human life and institutions and of all of our knowledge and study of the outside world, it may be reasonably contended that no other single phenomenon is a more important object of investigation. The scientific study of its different phases has already yielded writing, printing, telegraphy, the telephone, and the phonograph, besides making important contributions to psychology and physiology, as in the case of the doctrine of cerebral localizations which is a part of the basis of modern surgery. It is devoutly to be hoped that more nearly adequate provision may be made for the scientific study of language in all its phases. To which of our institutions of learning and research will fall the honor of leading in such a movement?

III. NEW TYPES OF APPARATUS

As to the development of new apparatus of the light-lever type, I would suggest two principles, to which we may provisional y give the names of sonoscope and sonograph, the first involving the elimination of all physical levers but retaining a receiving horn and diaphragm, the second eliminating all resonating and physically vibrating parts, and using a light-lever

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[17] Science of Musical Sounds, chs. VII and VIII.

whose initial deflection is obtained by refraction as it passes through free sound-transmitting air.   The purpose is to develop, if possible, an apparatus combining great sensitiveness and high magnification with minimum distortion, and constructible at moderate expense in the average laboratory of limited means and equipment.[18]

The sonoscope.   The principle of the sonoscope is shown in three forms in figures 1, 2 and 3.   It consists essentially of a receiver horn *H*, with a thin mirror-diaphragm *D* (probably of silvered glass or mica, or perhaps of polished metal) from which
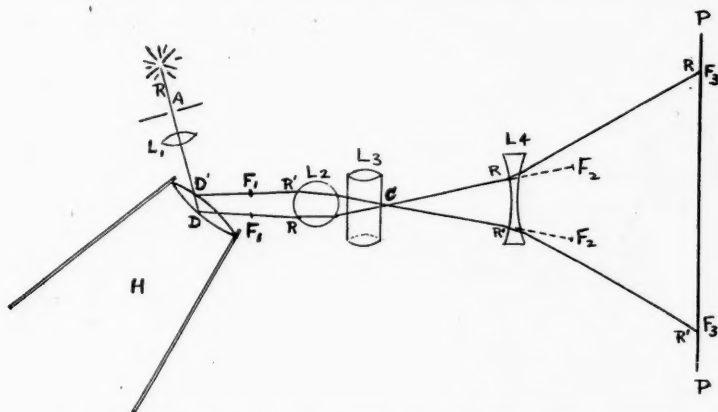

FIG. 1. PRINCIPLE OF THE SONOSCOPE, FORM A (HORIZONTAL SECTION)

a ray of light (or light-lever) *R* is reflected to the demonstration screen or photographic film *P*.   The ray is received through the pinhole aperture *A*, focussed by the lens L_1, falls at an oblique angle (say 30 degrees) on the vibrating mirror-diaphragm, whose varying vibratory positions *DD′* shift the ray to varying paths *RR′*.   These paths are nearly parallel or slightly divergent with an extreme separation of perhaps 0.005 or 0.010 of an inch, more or less, according to the amplitude of vibration which

proves feasible for the diaphragm. The divergence of the paths RR' is increased by refraction or reflection, thus causing the ray or light-lever to describe on the screen P an enlarged representation of the vibratory movements of the diaphragm D.

In form A (fig. 1), the paths RR' are made convergent by a lens of crossed glass or quartz fibers L_2L_3, whose proper radius of curvature (perhaps from 0.01 to 0.02 of an inch) must be experimentally determined. The paths RR' diverge again beyond the crossing point C, and when sufficiently far apart, have their rate of divergence increased by the concave lens L_4 (or by a convex glass-tube mirror, which can be made in the
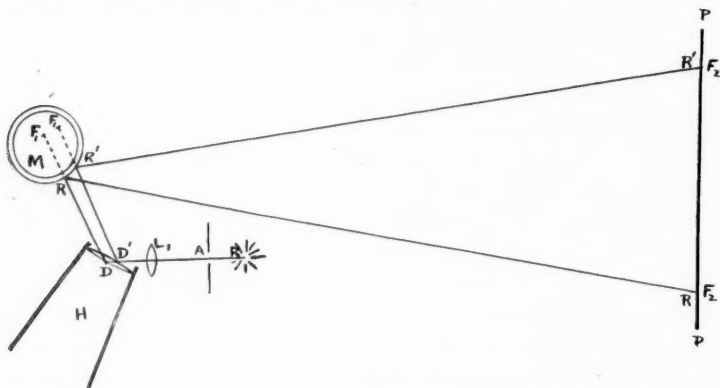

Fig. 2. Principle of the Sonoscope, Form B (Horizontal Section)

laboratory). The exact location of the various lenses must be such as to focus approximately the light-lever R on the screen P. The first focus of lens L_1 must fall between the diaphragm D and the fiber lens L_2L_3; the second focus F_2 of the lens L_2L_3 will fall beyond the crossing point C, because divergence within the ray before reaching the fiber lens L_2L_3 is greater than that between its paths RR'. The concave lens (or convex mirror) L_4 must be placed between the crossing point C and the second focus F_2, thus prolonging the focus to F_3 on the film or screen P.

In form B (fig. 2), a convex glass-tube mirror M replaces the lenses L_2L_3 and L_4 of form A. The first focus F_1 must fall be-

yond the mirror M, which prolongs the focus to F_2 on the screen P. Other factors are as in form A. It may be found advisable also to try two glass-tube mirrors instead of one. For the possible arrangement in that case, compare the place of the two mirrors in form B of the sonograph in figure 5.

In form C (fig. 3), a concave lens L_2 replaces the mirror M of form B. Other details are as in form B. The lens L_2 would have to be very small and might therefore be more difficult to obtain and adjust than the glass-tube mirror. Form C therefore seems to offer less promise of success than forms A and B.
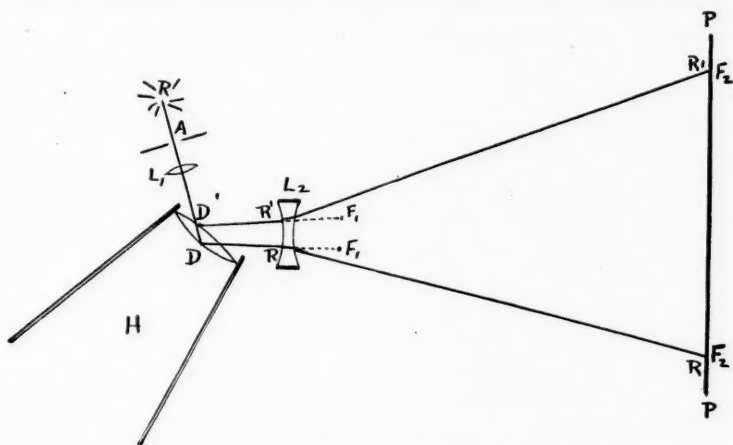

Fig. 3. Principle of the Sonoscope, Form C (Horizontal Section)

The sonograph. The principle of the sonograph is shown in figures 4, 5 and 6. It consists of a sound-proof cylinder SC and $S'C'$ completely cut across by an oblique opening OO comprised between two parallel planes. A ray of light R passing throug the aperture A and the collecting lens L_1, all in the first section of the sound-proof cylinder SC, thence passes through a parallelogram prism Pr_1 into the opening OO, through a second prism Pr_2 into the second sound-proof section $S'C'$, where it passes through diverging lenses or mirrors to the screen or film PP. The ray R is refracted away from the perpendicular as it passes
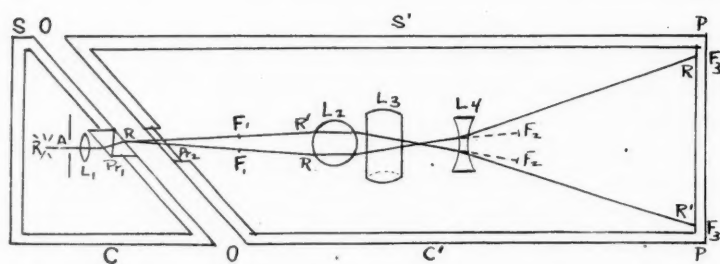
Fig. 4. Principle of the Sonograph, Form A (Vertical Section)
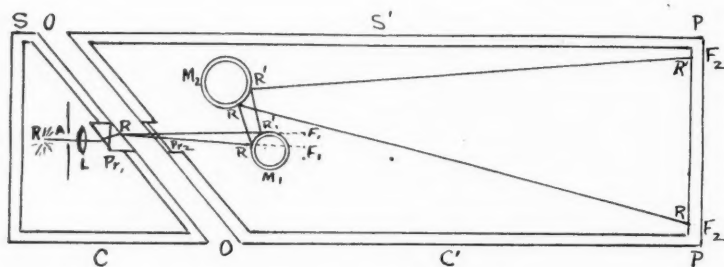

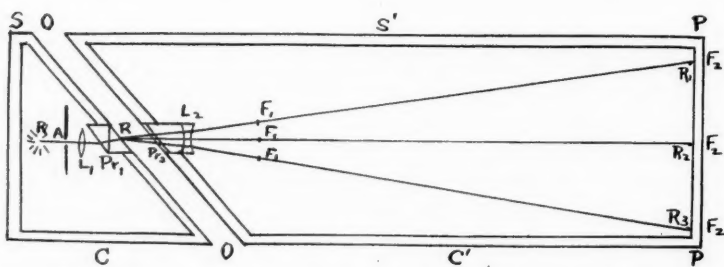Fig. 5. Principle of the Sonograph, Form B (Vertical Section)

Fig. 6. Principle of the Sonograph, Form C (Vertical Section)

from the prism Pr_1 to the open space OO.   If, at the same time · voice or other sound waves are passing through the free space OO, the refraction of R will vary slightly according to the successive rarefactions and condensations caused by the varying phases of the sound waves passing through OO, thus shifting the ray or light-lever into different slightly divergent paths RR and RR'. This divergence is increased by the lenses or mirrors, thus projecting on PP an enlarged sinusoidal record of the sound waves passing through OO.

Two modifications of the second prism Pr_2 will probably be found necessary in actual practice.   First, it would, if unmodified in form, tend to neutralize the divergence of the light-lever R effected by the varying air densities in the opening OO, since the refractive indices of the two prisms Pr_1 and Pr_2 would be reciprocal to each other for every density of air in the opening OO, while the air density in both sound proof chambers SC and $S'C'$ remains constant.   To avoid, this neutralizing effect, it will undoubtedly be necessary to concave either the first surface or both surfaces of the second prism Pr_2 at the point or small area where the light-lever R traverses it, the first center of curvature or concavity lying either at the point where the light-lever R emerges from the first prism Pr_1 or within the open space OO.   This would in effect introduce a minute concave or bi-concave lens in the second prism Pr_2 at this point.   Again, the second prism Pr_2 may have to be doubled, with a dead air space between its two parts, in order to preserve the sound proofing of the second chamber $S'C'$.

In form A (fig. 4), the arrangement of lenses and focussing is the same in principle as that of form A of the sonoscope, shown in figure 1.   This plan would probably necessitate the distance RL_2 (from the first prism to the fiber lens) to be relatively very great in order to allow the very slight divergence of the paths RR and RR' to become sufficient for the lens L_2L_3 to deal with it.   How great this difficulty will prove to be in practice can be determined by trial.

In form B (fig. 5), two convex glass-tube mirrors M_1 and M_2 replace the lenses L_2L_3 and L_4 of form A.   The focussing follows

the principle of form B of the sonoscope in figure 2.   This form
of the sonograph principle would seem to be more sure of success,
since the tiny tube mirror M_1 could deal with and magnify very
small divergences in the paths RR and RR', and probably need
not be as far from OO as would be necessary for the lens L_2 in
form A.

In form C (fig. 6), a simple concave lens is substituted for the
battery of mirrors or lenses of forms A and B.   Otherwise it is
the same in principle as form B.   The difficulty of length be-
tween the prism Pr_1 and the lens L_2 would probably be much
greater in this form than in form A.   Perhaps it could be partly
overcome by using an additonal concave lens between L_2 and F_1.

Whether or not the above suggestions prove to be practicable,
the problem of approximating a perfect graphic record of sound
vibrations must fulfil the conditions of eliminating all distortion,
suppression, extraneous addition, reinforcement and muffling.
In the final solution the light lever (or some electrical, magnetic
or x-ray substitute) will probably enter.   If a receiver horn and
diaphragm enter in, the form must be so shaped as to have the
widest range of equalized responsiveness to all forms of vibra-
tions, and the diaphragm must be of such form and texture or so
weighted as to avoid all self-vibration and unequal responsive-
ness.   Perhaps the outer ear and ear drum of man or other
animals still have suggestions to give us on these lines.   If
physically vibrating parts enter in, they must be of the minute
order of magnitude or vibrative amplitude which allow them to
vibrate fully and freely on the scale of normal sound-vibrations,
and so damped or adjusted as to eliminate muffling, reinforce-
ment and self-vibration. Mechanical construction (if any
remains) must be practically perfect.   Probably the final solu-
tion will come along the line of some principle which (like the
sonograph principle suggested above) uses a light-lever whose
initial deflection is effected by refraction as it passes through
free sound-transmitting air.

THE MANIPULATION OF THE TELESCOPIC ALIDADE IN GEOLOGIC MAPPING

KIRTLEY F. MATHER

INTRODUCTION

The ability to use the telescopic alidade in plane-table mapping is absolutely indispensable to the geologist engaged in investigating oil and gas resources of any region. Even though he may be assisted by an "instrument man," to whom is entrusted the actual operation of alidade and table, final responsibility for the accuracy and speed of the work rests with the geologist. No geologist bent upon applying the principles of geology to the search for, and production of, petroleum may consider his training complete until he has had considerable experience using plane-table and telescopic alidade. Manipulation of the alidade is sufficiently simple to permit the tyro to grasp quickly its more obvious details, but at the same time offers opportunities for ingenuity and resourcefulness sufficiently complex to be worthy the mettle of the most expert.

It is the purpose of this paper to assemble in convenient form certain of the more successful methods of manipulating the alidade, which have been developed during the last few years by many of the workers with this instrument. It is hoped that this presentation will be sufficiently simple to enable the beginner to make use of it, and at the same time sufficiently comprehensive to be a desirable reference work for even the instrument man of wide experience. The paper does not include a description of field methods of mapping, either by traverse or triangulation; for such a description reference should be made to

the work of Wainwright,[1] Ransome,[2] Wegemann,[3] Stebinger[4] and others.

The writer is deeply indebted to his comrades of the United States Geological Survey, especially to K. C. Heald, E. Russell Lloyd and Eugene Stebinger, for much of the information assembled here. He is also obligated to the Bausch and Lomb Optical Company and to W. and L. E. Gurley for illustrations and tables reproduced from their catalogs and manuals.

DESCRIPTION OF THE ALIDADE

The telescopic alidade consists essentially of a telescope attached by a transverse axis to a base plate, one edge of which bears a fixed and approximately parallel relation to the line of sight, and so supported as to permit the telescope to be elevated or depressed in a vertical plane. Of the many different models on the market, that most suited to the needs of the petroleum geologist is the "miniature" or "explorer's" alidade, designed in 1909 by H. S. Gale of the United States Geological Survey, some form of which is now produced by each of the leading makers of surveying instruments. This alidade is illustrated in figure 1.

The telescope is a metal tube fitted with an object-glass at one end, an eyepiece at the other, and between the two a reticle holding cross-hairs. A diagrammatic longitudinal section of the telescope, showing the paths of light rays passing through it, forms figure 2.

The object-glass ordinarily comprises a crown lens and a flint lens so shaped and arranged as to gather the rays of light from an object and form a small inverted image in the plane of the

[1] Wainwright, Plane-table manual. U. S. Coast and Geodetic Survey, Rept. for 1905, App. 7, 1906.

[2] Ransome, F. L., The Plane-table in detailed geologic mapping. Econ. Geol. vol. 7, pp. 113–119, 1912.

[3] Wegemann, C. H., Plane-table methods as applied to geologic mapping. Econ. Geol., vol. 7, pp. 621–637, 1912.

[4] Stebinger, Eugene, Control for geologic mapping in the absence of a topographic base map. Econ. Geol., vol. 8, pp. 266–271, 1913.

cross-hairs. These lenses are contained in a separate smaller tube which may be slid in or out of the telescope tube by means of a rack and pinion turned by the focusing screw on one side of the telescope in front of the transverse axis. This is necessary to define sharply the image of distant or near objects at will, or in other words to provide a means of bringing the objects in the field of vision into focus.

The eyepiece is similar to a microscope; its purpose is to magnify the cross-hairs and the image thrown by the object-glass. It may be adjusted to suit the eye of the individual observer by twisting the knurled ring at the end of the telescope tube. This
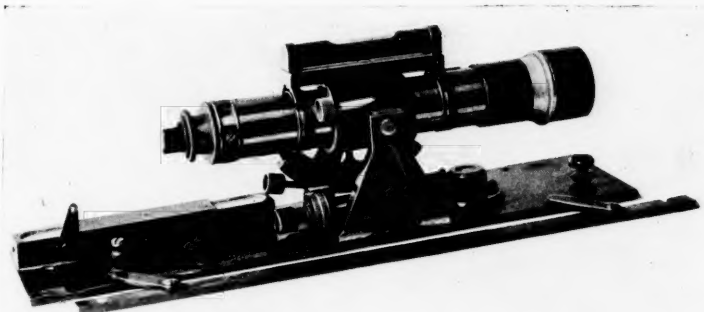

Fig. 1. The Gale Alidade with Stebinger Gradienter Drum Attachment and Detachable Parallel Rule; Striding Level in Place and Compass Needle Released. (Photograph from U. S. Geological Survey.)

shifts the eyepiece toward or away from the cross-hairs. Once properly adjusted there is no reason for changing the position of the eyepiece unless the instrument is used by another observer.

If the image formed by the object-glass is not in the same plane with the cross-hairs, any movement of the eye is likely to cause an apparent movement of the image with respect to the cross-hairs. This is called *parallax*. The effect is similar to that produced in looking through a window, where any movement of the eye causes an apparent movement of objects outside. Parallax may render accurate work impossible. To remedy it the image and the cross-hairs must be brought into the same plane. Two steps are necessary.

(1) Point the telescope toward the sky and move the eye-piece in or out until the cross-hairs are as well defined as possible, i.e., in perfect focus. . . . .

(2) Direct the telescope to the object and focus the object-glass as usual, keeping the eye on the cross-hairs until the image appears in sharp focus. Test by moving the eye from side to side, and if necessary move the object-glass slightly until parallax disappears.

The more accurate the work the more care should be used to eliminate parallax, while the higher the power of the telescope the more difficult it is to do this.[5]

At the ocular end of the eyepiece is a fixed prism which deflects the rays of light at right angles to their line of passage through the telescope and at the same time produces an erect image of the field. All observations are to be made while the operator is
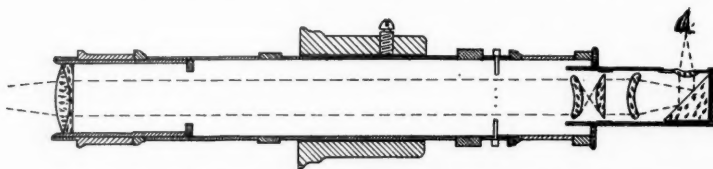

FIG. 2. DIAGRAMMATIC LONGITUDINAL SECTION OF ALIDADE TELESCOPE;
PATHS OF LIGHT RAYS INDICATED BY BROKEN LINES

looking directly down into the eyepiece prism. Some alidades are fitted with a "periscope" or tubular roof above the eyepiece prism in which is housed a lens for the reversal of the image. When this is wanting, images in the field appear right side up but reversed from right to left. To keep maximum illumination of an undistorted field as observed through a roofed prism entails precision grinding of the highest order of merit; this is obviously very expensive so that there exists some doubt as to whether it actually pays to correct the relation of the elements of the field in this particular.

The magnification of miniature alidades is ordinarily 16 or 20 diameters.

[5] J. C. Tracy, Plane Surveying. John Wiley and Sons, New York, 1907, pp. 555–6.

The cross-hair ring, or reticle, is placed so as to be at a principal focus of the object-glass as well as at a focus of the eyepiece. Its position is indicated by four screws or capstans on the outside of the telescope tube. The cross-hairs are spider webs, or very fine platinum wires, almost invisible to the unaided eye. They are generally four in number and are fastened immovably with shellac to the brass ring before it is inserted in the telescope. Two of the hairs cross the center of the ring at right angles to each other; their purpose primarily is to define the line of sight. The other two are parallel to one of these and spaced equidistant on either side of it; they are the *stadia hairs* and are used primarily for measuring distances. In the Gale design of alidade, none of these hairs are adjustable with respect to each other, but the whole reticle may be moved by means of the four screws which hold it in place.

It is very important for purposes of adjustment to understand how the capstan screws control the movement of the cross-hair ring. . . . . The holes in the telescope through which the screws pass are not threaded; on the contrary, they are a little larger than the screws, so that when the latter are loose the whole ring may be turned slightly by moving the four capstan heads simultaneously around the outside of the telescope until one cross-hair is vertical and the other horizontal. When the capstan screws are tight, each screw. presses a curved washer (shown in the photograph) against the outside surface of the telescope. When one screw is loosened and the opposite screw tightened, the whole ring is drawn toward the tightened screw (since the holes in the shell of the telescope are smooth) until the loose screw and its washer are brought into contact again with the outside of the telescope. Notice that before tightening one screw the opposite screw should be loosened, otherwise the ring cannot move and the screw-thread may be stripped. By loosening the lower screw and tightening the upper screw, the whole ring may be drawn upward, or by reversing the process it may be drawn downward. Likewise by working the side screws in a similar manner, it may be drawn to one side or the other. All this may be done without turning the ring, i.e., one hair may be kept vertical, the other horizontal.[6]

[6] J. C. Tracy, loc. cit., p. 550.

The telescope tube is inserted in a short sleeve at its mid-length, which forms a part of the transverse axis by means of which vertical oscillation is made possible. The telescope is mounted revolvably between 180-degree stops in this axis-sleeve and is prevented from turning on its longitudinal axis in the process of focusing either by a plunger at the under side or by a clamp ring screwed at one end of the sleeve. At either side of this axis-sleeve the telescope is surrounded by a "red metal" collar, accurately turned to the axis of rotation defined by the sleeve. These collars are for the support of the striding-level by means of which the telescope is brought into the plane of the horizon. The striding-level is removable and when not in use is held in a corner of the base plate by a binding post. A similar post is attached to the top of the axis-sleeve and when the striding-level is put in place for observations, as in figure 1, it is snapped down over the shoulder on this post, which merely prevents it from falling off in case the alidade is tilted and should not support it in any way. The wyes, trued to the same angle, at either end of the bubble glass then rest on the metal collars.

The striding-level itself is a glass vial, partially filled with a non-freezing liquid, ground on the inside to the arc of a circle with long radius.

The more uniform this curvature is throughout the length of the tube the more regular will be the motion of the bubble, and the greater the radius of curvature the greater the sensitiveness of the bubble. Within reasonable limits the more sensitive the bubble the more perfect the work, though a very sensitive bubble may be too unsteady for many purposes; on the other hand a sluggish bubble, though it may give the appearance of steadiness to an instrument, and an impression that it "keeps" its adjustment, is incapable of accurate work. . . . .

The line tangent to the circular arc of the tube at its middle point, or a line parallel to this tangent, is called the *axis of the bubble-tube*. When this axis is horizontal the bubble will be in the center of the tube. Should the axis become slightly inclined the bubble will move toward the higher end of the tube in proportion to the angle made by the axis with the horizon. The glass tube is usually graduated on top by marks 0.01 feet (or 2 mm.) apart. The value of a level-bubble is usu-

ally expressed by the change which takes place in the inclination of the axis when the bubble moves over a single space. Thus in a 1-minute level for a displacement of one division the inclination changes 1 minute, and in a 20-second level it changes 20 seconds.[7]

Ordinarily, the alidades in use by geologists are fitted with 60-second levels, but it is preferable where possible to use a 20-second level, a change which at low cost adds greatly to the possible accuracy of the work.

The telescope and axis-sleeve are carried on standards about two inches high to permit a reasonable vertical swing of the telescope. The transverse axis projects beyond the bearings which cap these standards and is gripped on the right by the vertical clamp. This is tightened or loosened by the knurled screw, set close to the top of the right hand standard. When loosened, the telescope swings freely through an arc of about 45 degrees in the plane at right angles to the transverse axis. When tightened, the swing of the telescope is limited by the play of the clamp arm, a downward extension of the clamp proper. In one style of miniature alidade, this arm is held by a horizontal spring against the point of a horizontal tangent screw working through the lower part of the telescope standard. In another model this arm is expanded, and itself carries the tangent screw and horizontal spring bearing against a stud fixed to the inside surface of the right hand standard. In either, the rotation of the tangent screw causes the telescope to be slowly elevated or depressed. The screw is therefore spoken of sometimes as the fine adjustment or micrometer screw. A graduated drum may be attached to this screw, as in figure 1, which as explained later may be used in the measurement of distances or the determination of vertical angles. When thus equipped the tangent screw is known as the *gradienter screw*. Or if the special gradienter drum provided with a celluloid index, as suggested by Eugene Stebinger, United States Geological Survey, is attached, it is frequently referred to as the *Stebinger drum and screw*.

[7] J. C. Tracy, loc. cit., p. 544.

Fixed to the opposite end of the transverse axis and attached just outside of the left hand standard is a graduated arc, generally of about 130 degrees duration, by means of which vertical angles are measured. It is therefore referred to as the *vertical arc*. It moves past a shorter arc of similar curvature, which carries the vernier scale and is adjustable by means of a horizontal screw working through the left hand standard in much the same way as does the micrometer screw on the right standard.

The base plate is firmly attached to the telescope standards and is primarily intended to form a straight edge, parallel with the line of sight through the telescope and maintaining that fixed relation no matter in what direction the instrument is pointed. To facilitate the use of the straight edge, the right side of the plate is beveled and graduated in linear measure; it is known as the *fiducial edge*. In the miniature alidades there is attached to one corner of the base plate a compass box, or *declinatoire*, housing a compass needle which has a possible oscillation of about 10 degrees. The compass is not intended for the reading of angles of departure from magnetic north, but solely for the designation of the magnetic meridian; therefore the only markings are the zero points at either end of the needle. The needle is either of the tubular or the steel bar variety, mounted generally on a sapphire-tipped pivot, and provided with clamping device and adjustable balance. The latter must be adjusted by the user for different latitudes by sliding it along the needle until it is properly balanced. A declinatoire so constructed as to make the needle easily accessible is therefore preferable. There is also fixed to the base plate, generally near the objective end of the telescope, a *bull's eye level* by means of which the plane table on which the alidade is resting may be quickly brought into an approximately level attitude.

An "extra" attachment which has proved to be a great time- (and therefore money-) saver is the *parallel rule*, shown in figure 1. A brass straight-edge, $\frac{1}{2}$ inch wide and as long as the alidade base, carries two brass bars, 1 or $1\frac{1}{4}$ inch long, pivoted near either end, with the pivot centers in a line parallel to the straight edge. Set in the free end of each short bar is a round

lug which fits into a circular hole bored in the base plate near its margin. The centers of these holes are in a line parallel to the fiducial edge, and the short bars are of equal length. Therefore the removable straight-edge, when put in place, is parallel to the fiducial edge and may be shifted close to it or out away from it without losing its parallelism. In "lining-in" a distant station, all the time involved in getting the fiducial edge exactly on the occupied station point is saved. The line of sight is mechanically shifted in parallel position to the proper place on the map. Similar holes may be bored near the left side of the alidade base, and the same straight-edge attached there for work close to the left margin of the table, but if that change is made, the table must be re-oriented because of the probable change in the relation between the line of sight and the ruler edge. The parallel rule, when detached, may be conveniently carried in a pocket sewn across one edge of the alidade case.

The complete instrument weighs about 3 pounds, stands between 3 and 4 inches in height, and is 10 to 12 inches in length. It is fitted into a sole-leather case with shoulder strap for carrying in the field.

MANIPULATION OF THE ALIDADE

To determine bearing

In traversing with plane table and alidade, the location of an unplotted point is determined by its direction and distance from another point which has previously been plotted on the plane table sheet. Instead of determining this direction in terms of a compass or angle reading, to be later drawn on the map in the office, as is done with transit or theodolite, the determination and the plotting of the bearing to the distant point are accomplished by a single operation. This makes necessary the accurate orientation of the plane table sheet so that the lines drawn on it will, whenever the plane table is set up for use in the field, be parallel to the position which they occupied at every preceding set-up.

Plane table orientation. Orientation of the plane-table sheet is ordinarily accomplished by means of the magnetic needle housed in the compass box attached to the base of the alidade. The fiducial edge of the alidade base is placed along a line ruled on the plane table sheet, and the needle liberated from its rest so that it swings freely in its box; the table is then rotated until the needle points to the north and south marks at either end of the compass box. Thereafter, whenever the same alidade is placed on the same side of the same line so that the same edge of its base coincides with the line, and by rotating the table the freely vibrating needle is made to come to rest at the same point, the sheet is in approximately parallel position. The orientation line ruled on the plane table sheet should extend the full length of the alidade base, or should consist of two shorter lines, three or four inches in length, drawn to each extremity of the base. An arrow should be sketched at the north end of the line or lines; the compass box is so attached to the alidade that when the needle comes to rest in the line of the marks at its ends the line of sight through the telescope leads approximately toward magnetic north.

Although of course not necessary, it is very desirable and universally customary so to draw the orientation line that the sides of the plane-table sheet coincide with the four cardinal directions. This may be accomplished in several ways, a few of which will be mentioned here. In many parts of the country, the public roads have been accurately surveyed along section lines; commonly the fences have been similarly placed in a true north-south or east-west direction; or again, section corners may be so situated that one corner-post—or a flag placed directly above it—may be seen from another. If the plane table can be set up in the line thus determined by road or fence or land net, the ruler-edge of the alidade should be placed along the margin of the plane table sheet, or along the line previously drawn to represent the meridian of the map, and the table rotated until the line of sight through the telescope falls along the visible line thus defined. The table locked in that position, the alidade is moved to the desired part of the sheet and turned until the

compass needle comes to rest in the line of its indicators.   The
orientation line is then ruled along the alidade base.   The angle
between that line and the meridian of the map will be deter-
mined by the local magnetic declination as modified by any
divergence which may be present between the line of sight of
the alidade, the fiducial edge of the alidade base, and the line
defined by the compass needle and its indicators.   These three
lines need not be parallel; the work will not be affected by diver-
gence between them.

Another method of orienting the table before drawing the
orientation line makes use of a Brunton or other compass, care
being taken to make allowance for the departure of magnetic
from true north, and depends upon previous knowledge of the
magnetic declination in the region.

Or, again, it may be necessary or desirable to draw the orien-
tation line on the plane-table sheet before it is oriented for the
first time.   It must then be assumed that the line of sight, the
compass line, and the alidade straight edge are parallel; the error
in orientation thus involved will in most cases be of no conse-
quence.   The orientation line is plotted so that the angle be-
tween it and the meridian line is equal to the magnetic declina-
tion.   This angle may be scaled off by means of a protractor, or
if more accurate drafting is desirable, a trigonometric function
may be used.   Draw a line 10 inches long in the desired position
of true north; at one end erect a perpendicular such that its
length in inches is 10 times the tangent of the angle of declina-
tion; connect the other end with the end of the perpendicular
by a line which is the desired orientation line.   This is more
accurate than plotting the angle with a protractor which has a
radius of only 3 or 4 inches for in that case any error in plotting
is greatly multiplied when the line is extended to the necessary
length of 12 or 15 inches.

The whole matter of accurate situation of the orientation line
is of slight importance when working upon a plain sheet, but is
of the greatest importance if the work is to be done upon a sheet
on which the land net has been previously plotted, or upon a
base map prepared by other surveyors, as for example an enlarge-

ment of a portion of a United States Geological Survey topographic map or a Land Office map.

The use of the magnetic needle for orientation of a plane-table sheet requires the utmost care. The length of the needle from its pivot to either end is only $1\frac{1}{2}$ to 3 inches, and lines will frequently be drawn on the map which are much longer than that. Errors in observing the needle may therefore be multiplied during the progress of the work and thus may become of more than trivial importance. Careful attention should be paid to see that the needle is swinging freely; a pocket magnifier should be used in observing its position with respect to the indicators; observation should be made from directly behind the instrument so that the observer sights along the needle from above rather than from the side.

In many instruments the needle is not perfectly straight, or the two indicators and the needle pivot are not in a straight line; it is then best to regard only one end of the needle, being careful always to use that end and not the other. Or, again, the needle points may be blunt and the indicators of considerable width; in that case select a definite relationship of needle point to marker and adjust the table or alidade so that the needle always returns to that relationship each time the map is oriented.

The surveyor must, moreover, be always on guard lest steel or iron bodies in proximity to the compass box deflect the needle. Articles about his own person should receive his attention; he should stand so that his pocket knife is at least a foot from the needle; a Brunton or other compass must be kept at least 3 feet distant and must, therefore, be removed from the belt before attempting to orient the table; the margin of safety for a geologic hammer is a little less than 2 feet, and it may therefore be left in the belt if carried in the rear and if the surveyor stands well away from the table in observing the needle; a harmless appearing, leather-covered metal binocular or monocular case, if permitted to come within 2 feet of the needle, may lead to the erroneous conclusion that one is endowed with a superabundance of personal magnetism. Metallic bodies in the general vicinity

of the plane table may deflect the needle and introduce grave errors into the work. The table should never be set up for compass orientation within 10 feet of a wire fence, within 15 feet of a pump-jack, less than 10 feet away from a pipe-line, buried or on the surface, closer than 10 feet to a railroad track, or nearer than 20 feet to an automobile.

The plane-table sheet may also be brought into correct orientation without the use of the compass needle by means of foresight lines. This necessitates the planning of one's work for days or even weeks in advance, but should be used in all triangulation work and may be used in orienting the table at any set-up where for some reason compass orientation is unwise. Assume that two stations are clearly visible, the one from the other, and that the table is set up in correct orientation at one, while the other has not yet been occupied. A line, the fore-sight, is drawn from the point representing the occupied station in the direction of the distant objective. It should be drawn the full length of the alidade base, extending from the plotted point away from the unplotted as well as toward it, even though the point when plotted will be only an inch or two away from the occupied station. Or if preferred, the fore-sight line may be discontinuous, covering the estimated location of the distant station on the map and including a line an inch or so in length at either end of the alidade straight edge. When, later, the station to which the fore-sight line has been drawn is reached in the progress of the field work, the table should be approximately oriented with the eye, the alidade base placed along the fore-sight line so that the telescope points back toward the old station, and the table rotated until the distant signal is bisected by the vertical cross hair of the alidade. The most likely place for error to enter into this manipulation is in the adjustment of the alidade base to the ruled fore-sight line; a pocket magnifier should be used in the placing of the alidade, if the most accurate results are desired.

Still another method of orientation makes use of the Baldwin Solar Chart. The angle between the apparent position of the sun and true north is graphically determined by means of this chart which is so constructed that when turned until the proper

pivot point on an arrow and the "sun-time point" on a latitude arc are on a line parallel to the shadow cast by a plumb-line upon a level table the arrow points true north. A copy of this chart and full directions for its use may be found in Topographic Instructions of the United States Geological Survey, pp. 136 to 141.[8]

Lining in the station. After the table has been properly oriented at a station, the location of which has been plotted on the map, the bearing of any visible object may be drawn directly. The alidade is moved until the straight edge touches the side of the needle-hole or pencil dot representing the occupied station and the vertical cross-hair in the telescope bisects the distant object, the bearing of which is desired; a line drawn along the straight edge will then represent the compass-bearing plotted to position on the map under construction.

The best method to pursue in lining-in a distant station is to grasp the ends of the alidade base with either hand; shift the instrument until the line of sight through the telescope falls upon the desired objective and the fiducial edge rests within an inch or two of the dot locating the occupied station; then move the alidade diagonally forward and to the right, keeping the vertical cross-hair on the distant object, until the ruler edge touches the proper point. If the alidade is equipped with a parallel-edge ruler, it is only necessary to place the instrument somewhere near and to the left of the plotted point in such a position that the vertical cross-hair cuts the distant station; then push the parallel straight-edge outward until it touches the proper point. Some surveyors make it a practice to stick a needle vertically into the plane table at the point representing the occupied station, and to pivot the alidade on the needle when lining-in a station. This practice is not recommended. Although it is an easy way for the novice to increase his speed, it involves inaccuracies of considerable import. If the needle is inserted far enough to hold its upright position, it makes a hole several times as large as necessary; the point becomes a space which on

[8] Government Printing Office, Washington, D. C., 1918; price 35 cents.

the customary scales represents an area on the ground, 30 to 60 feet in diameter.

Lines representing bearings should be drawn with the chiseled edge of a 9-H pencil, being careful always to hold the pencil at the same angle and to see that the contact of rule and paper is perfect.   By placing the ruler edge in a position tangential to the tiny circle formed by needle-hole or dot, the line when drawn should exactly cut the center of the "point."   If the distant station is subsequently to be occupied and orientation there is to be by back-sight, the fore-sight line should be the full length of the alidade base; if not, the fore-sight line may be short, covering only the estimated position of the point.   It is better not to draw lines through the dot or needle-hole representing the occupied station; break the line for a fraction of an inch on either side.

To measure distance

Distances are directly determined with the telescopic alidade by means of the stadia hairs and rod.   Stadia work depends upon the hypothesis that the sizes of objects required to produce an image of fixed size in the telescope are directly proportional to their distances from the point over which the telescope is set. This hypothesis is not rigidly correct, but the theoretical error is small and the practical error negligible.   The limits of the image in the telescope are fixed by the parallel stadia hairs in the reticle.   The object most convenient to use is a graduated rod.   In the alidades commonly used by the geologist, the stadia hairs are so adjusted that the ratio between the distance from the telescope to the rod and the distance intercepted on the rod by the upper and lower hairs, when the rod is held at right angles to the line of sight and to the hairs, is as 100 to 1.   If the rod is 100 feet from the instrument, the outer hairs appear to subtend 1 foot upon it; if 1200 feet distant, 12 feet of the rod will appear between them (see figure 3).   Moreover, the middle cross hair in the reticle is placed as nearly as possible equidistant from the outer two.   Therefore, the distance subtended on the rod by the middle hair and either outer hair is 1/200 the distance of the

rod from the telescope. In some alidades, "quarter hairs" are placed so that they bisect the spaces between the outer and middle hairs. The ratio for them is, of course, 1 : 400; with an instrument so equipped distances up to 400 times the length of the rod may be read directly. Sketches showing the relation of a stadia rod to the field of view at different distances are shown in figures 4, 5 and 6.

In practice, then, it is necessary only to raise or lower the telescope until the two stadia hairs appear to rest on the rod, one intersecting a primary division and the other falling across a divided foot. Read the intercept and multiply that distance by 100 if the outer hairs were used, by 200, if the middle and one of the
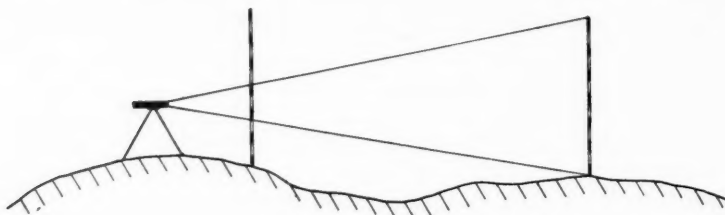
FIG. 3. DIAGRAM ILLUSTRATING THE STADIA PRINCIPLE

The diverging lines representing the projection of the stadia hairs form intercepts on the rods proportional in length to their distance from the instrument.

outer hairs were used, or by 400, if the "quarter hairs" were read. Use the most distant hairs the intercept of which may be read, for otherwise the observational error is multiplied by 2 or 4, as the case may be. Also place the hairs as near the top of the rod as possible so as to minimize the error of refraction.

As a matter of fact, the distance in the line of sight to the rod, thus determined, is not measured from the center of the instrument but from a point in front of the telescope objective at a distance equal to F, the focal length of the objective. Therefore the distance from center of alidade to rod is represented by the formula

$$D = 100s + F + c,$$

where s is the intercept on the rod between the outer hairs, and c the distance from center of instrument to objective. $F + c$ is practically a constant for a particular alidade, as it varies only
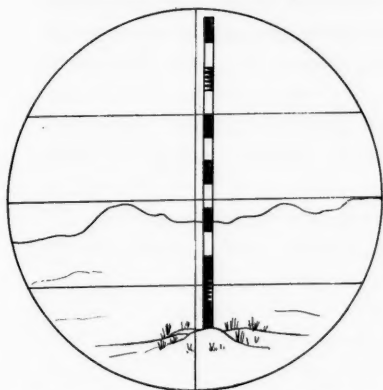

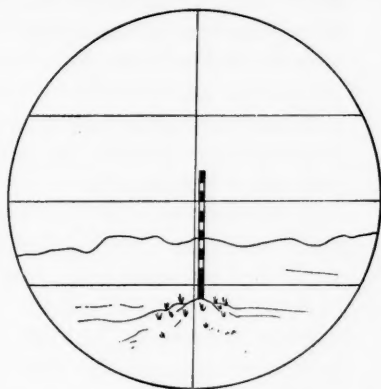FIG. 4. STADIA ROD IN THE FIELD OF VIEW AT A DISTANCE OF 720 FEET

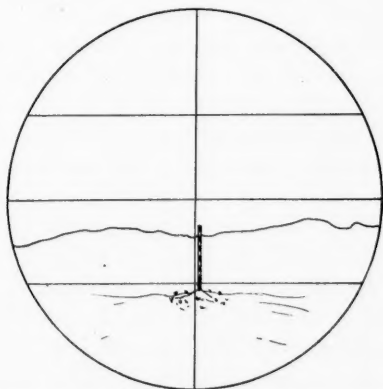FIG. 5. STADIA ROD IN THE FIELD OF VIEW AT A DISTANCE OF 1740 FEET

FIG. 6. STADIA ROD IN THE FIELD OF VIEW AT A DISTANCE OF 3360 FEET

with the focusing of the instrument.   For ordinary purposes it may be taken as 1 foot, a space so short as to be altogether negligible in most work undertaken by the geologist.

Long sights.   Occasionally, it is necessary to measure distances greater than 200 times the rod length with an alidade equipped only with three stadia hairs.   Several different methods of procedure are available; the choice of the one to use depends upon the equipment of the instrument, the geographic environment, and the custom of the individual surveyors.   Some of the methods are in effect schemes to provide a longer rod.   Others depend upon trigonometric principles.   The method numbered 5 is probably best suited to the more common conditions met in geologic mapping.

1. Rotate the telescope 90 degrees in its sleeve so that the stadia hairs are vertical instead of horizontal. Signal rodman to mark his station with a flag or to select a certain sapling or post for his station.   Place one hair on the station and signal rodman to move at right angles to the line of sight until the rod, held vertically, is in line with the other stadia hair.   The rodman will then measure the distance horizontally on the ground from his second position to his first, using the rod as a measuring stick, and report the result to the instrument man.   Distances of 4000 to 7000 feet may be determined with a fair degree of accuracy by this method.   It may be used to advantage only when the two men are able to communicate freely by signals such as the two-arm semaphore code.

2. Rotate the telescope as before.   Signal rodman to hold rod horizontally and to be prepared to move laterally so that the base of the rod will occupy the point now occupied by its top. Intersect base of rod with one stadia hair.   Signal rodman to move over in the desired direction a sufficient number of rodlengths so that the other stadia hair will finally intersect the rod. Read intersection; add the number of feet indicated by the length of the rod multiplied by the number of moves; multiply by 100 or 200 depending upon which hairs were used.

3. If instrument is equipped with a Stebinger gradienter drum attached to the fine adjustment screw, proceed as follows: Place bottom hair on lowest visible primary division of the rod; read and record Stebinger.   Turn Stebinger drum until middle hair rests on the top of the rod; read and record Stebinger.   Take

the difference of the two Stebinger readings; turn an equal number of divisions in the direction which brings the middle hair down onto the rod; observe the number of feet between the top of the rod and the intersection of the middle hair. Add this to the length of the rod which was above the bottom hair at the first reading; the sum multiplied by 200 is the horizontal distance. For example:[9] 12 feet of the rod are entirely visible and the middle hair is well above the rod when the bottom hair rests 12 feet below its top. In that position the Stebinger drum reads 24. Turn down until middle hair touches the top of the rod; Stebinger reading is now 60. The difference between the two readings is 36. Turn down 36 divisions more, to 96. The middle hair now intersects the rod 3.4 feet below its top. The horizontal distance is $200 \times (12 + 3.4)$ or 3080 feet.

4. If instrument is equipped as in 3 and there is at hand a table, previously prepared for this particular instrument, showing Stebinger factors,[10] i.e., the differences in elevation at the unit distance of 100 feet corresponding to the vertical swing of the telescope denoted in divisions of the Stebinger drum, proceed as follows: Place one hair on the top of the rod; read and record Stebinger. Turn down until that hair cuts the lowest visible primary division of the rod; read and record Stebinger. Take the difference of the two readings. Repeat for each of the other two hairs. The three results should check. Select from the table the Stebinger factor corresponding to that number of divisions. Note the number of feet passed over on the rod; multiply it by 100 and divide by the factor. The result is the horizontal distance. For example: 13 feet of the rod are visible. With the middle hair resting on the top of the rod, the Stebinger reading is 62. When the middle hair is turned down to the primary division 13 feet lower, the reading is 106. Difference of the two readings is 44; corresponding factor is 0.4111; horizontal distance is $1300 \div 0.4111 = 3160$ feet.

[9] This, and the following examples apply only to those instruments in which a clock-wise rotation of the Stebinger drum depresses the objective end of the telescope.

[10] The preparation of such a table and the mathematical principles on which it is based are discussed in subsequent pages of this paper.

This method is frequently employed by ingenious surveyors to good advantage in determining distances without the use of the stadia rod. Any two points, one above the other, at known distances apart suffice; two flags at a measured interval, the crown plate and girths (commonly eight feet apart) of a standard derrick, the eaves and lower copings of a church tower, are listed merely as suggestions. If the location of such a target is plotted, the surveyor may "shoot himself in," with a fair degree of accuracy, at any point from which it is visible.

5. If alidade is equipped as in 3, an alternative method which may be used is as follows: Place middle cross hair on top of rod; read and record Stebinger, denoting the record as A. Turn down until middle hair intersects the lowest visible primary division; read and record Stebinger (record B). Turn down until top hair rests on top of rod; read and record Stebinger (record C). Compute distance by the formula

$$L = 200\, r\, \frac{C - A}{B - A},$$

in which D represents the distance, r the length of the rod above lowest visible primary division, and A, B, and C, respectively the three readings of the Stebinger drum. For example: a 13-foot rod is entirely visible. The middle hair on top of rod gives a Stebinger reading of 31; middle hair on bottom of rod gives a reading of 54; top hair on top of rod gives a reading of 78.

$$\text{Distance} = 200 \times 13 \times \frac{78 - 31}{54 - 31} = 5300\,\text{feet.}$$

The formula may be more easily recalled if one has grasped the principle upon which it is based. The Stebinger difference, C–A, is theoretically a constant, the measure of the angle between the rays converging from the top and middle cross hairs to the focus of the telescope. If the rod at the distant point were of sufficient length, the intercept subtended by this angle could be read and, multiplied by 200, would give the distance to the rod. That is, if i be taken to mean the length in feet of that hypothetical intercept,

$$i = D \div 200.$$

But

$$i : r :: C\text{--}A : B\text{--}A,$$

for the Stebinger difference $C\text{--}A$ is the measure of the angle defined by the chord i and $B\text{--}A$ is the measure of the angle defined by the length of the rod at the same distance.   Therefore,

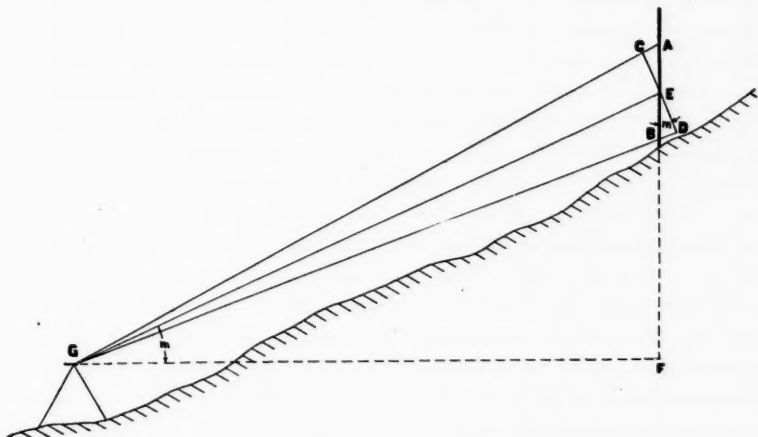$$(D \div 200) : r :: C\text{--}A : B\text{--}A,$$

or

$$D = 200\, r\, \frac{C - A}{B - A} \cdot$$

Fig. 7. Diagram Illustrating the Stadia Principle applied to Inclined Sights

Inclined sights. This discussion of the measurement of distances with the stadia has been based on the assumption that the rod is always held perpendicular to the line of sight and that the desired distance is to be measured along that line. As a matter of fact, most of the sights in stadia work are taken not on a level, but on a slope or inclination, as suggested in the diagram, figure 7. Consequently if the rod is held vertically, the stadia intercept is somewhat more than it would be when held perpendicular to the line of sight, and an element of error is intro-

duced. This error amounts to 1 per cent of the distance for a gradient of 8 degrees, 2 per cent for 11 degrees, and 3 per cent for 14 degrees. It may obviously be corrected by tilting the rod so that it is perpendicular to the central visual ray from the telescope. This may be accomplished by attaching a short pointer to the rod at right angles to its face and aiming this pointer at the instrument when the sight is taken. It is, however, difficult to hold the rod steadily in this position and this corrects only one of the two discrepancies. It is therefore customary to hold the rod vertical no matter what the angle of slope may be and make the correction in the tables for distance and elevation. The second discrepancy is due to the fact that the distance to be plotted is the horizontal distance from telescope to rod, not the inclined distance. So far as plotting is concerned, this discrepancy, and therefore the angle of inclination, must be fairly large before it need be taken into account; how large depends upon the scale of the map, but for most work it may be neglected for all angles of less than 3 degrees. With an angle of $5\frac{1}{2}$ degrees this discrepancy amounts to about 1 per cent, which for a distance of 1000 feet is little more than the diameter of a needle hole on a scale of 1: 31,250.

The stadia tables ordinarily used include the correction for horizontal distance of inclined sights. In practice, such tables should be consulted before plotting distances determined by sights which depart more than 3 degrees from the horizontal. Reference to the accompanying diagram, figure 7, will make clear the mathematical formula upon which the correction tables are based. In the diagram, AB represents the intercept on the rod held vertically, CD the intercept on the rod held perpendicular to the line of sight from G, GE, the distance from table to rod in the line of sight, and GF the horizontal distance from set-up to station. The angle of inclination of sight and the equal angle between the two positions of the rod are indicated by m. By trigonometry,

$$CD = AB \cos m$$

and

$$GF = GE \cos m.$$

But

$$GE = 100\ CD = 100\ AB \cos m;$$

therefore, by substitution,

$$GF = 100\ AB \cos^2 m,$$

by means of which the horizontal distance may be computed from the rod intercept and the angle of inclination.

The correction to be applied to the observed distance on inclined sights may be determined without reference to tables or formulae by means of the Beaman stadia arc (see fig. 11) an attachment for the mechanical solution of the stadia problem, which will be described in greater detail in a subsequent paragraph. The arc carries two scales, a multiple scale and a reduction scale, having coincident zero points marked 50 and 0, respectively. The reduction scale is, of the two, the more distant from the adjustable index and gives percentages of correction that may be used to reduce observed stadia distances to horizontal. The adjustable index should be set opposite the zero of the reduction scale when the telescope is level. To get the necessary correction, simply read the same scale with the line of sight cutting the distant station. Reading to the nearest per cent is usually sufficient. For example: the reduction scale reads 3 with an observed rod intercept of 16.2; then 3 per cent of 1620 = 48.6; 1620 − 48.6 = 1571.4 = corrected horizontal distance.

Location of stations. The distance thus determined by stadia is scaled off on the line ruled in the direction of the rod station from the point representing the occupied station. The proper method is to place the fractional scale division on the plotted point and prick the new location with the needle, or mark it with a well sharpened pencil, at the even division at the end of the scale. This operation should be performed with the greatest care and preferably with the assistance of a pocket magnifier; more closure errors are to be attributed to careless plotting than to any other cause. If a needle is used, do not try to puncture a hole clear through the paper; push the needle point just far

enough into the paper to make a permanent indentation, being careful to hold the needle vertically.

Accuracy of the stadia method. The telescopic alidade and stadia rod are to be looked upon as instruments of precision; distances are not estimated, but accurately determined in well-conducted stadia work. Although essentially intended to secure rapidity rather than accuracy, the stadia method employed with due care to eliminate the chief sources of error is capable of attaining a high degree of accuracy.

Perhaps some of the most interesting results obtained with stadia, as showing its precision, were those obtained by Mr. J. L. Van Ornum in taking topography on the international survey of the Mexican Boundary. The whole of the boundary line was measured with the stadia, and a large portion of it by the chain, and always tied in by a system of accurate primary triangulation. Corresponding distances were found by stadia and chain and compared with the known distances as obtained by triangulation, with the following results:

Of five different stretches measured by the three methods, the total distance shown by triangulation was 99,110 meters, by stadia 99,025 meters, by corrected chain 99,041 meters. . . . . Other sections of the line were measured by stadia and triangulation, but not by chain. In all there were measured 182.5 miles by stadia which were triangulated and in which the total difference in length was plus 50 meters, or 1 in 5837. It may be noted that the chained distance was marked corrected chain, because in six measurements of the chained distance, dropping or omission of chain-lengths occurred which were detected in every instance by the stadia.[11]

To determine differences in elevation

Methods of determining differences in elevation by means of the telescopic alidade are even more numerous than those in vogue for measuring distances. The good instrument man will know several different methods and select the one best suited to the particular sight, depending upon the accuracy required, the inclination of the sight, the equipment of the instrument, and

[11] H. M. Wilson, Topographic Surveying. John Wiley and Sons, New York, 1910, pp. 241–2.

the necessity for speed.   The more commonly used methods will
be described in the order of their simplicity.

1. Direct readings on the rod.   Occasionally the difference in
elevation between plane table and rod is so slight that with level
telescope the middle cross hair intersects the rod.   The vertical
distance from the bottom of the rod, or from any other selected
point on it, to the point of intersection may be read directly
from the graduations on the rod's face.   Care must be exercised
to prevent the confusion of the top and bottom stadia hairs with
the middle cross hair.   It is the visual ray projected by the
middle hair that is parallel to the striding level and therefore is
horizontal when the level bubble is centered.

But, suppose that when the instrument is level, the middle
hair falls above or below the rod while one of the other hori-
zontal hairs cuts the rod.   In practice it is customary first to
read the rod intercept for distance and second to determine the
vertical difference between instrument and rod; therefore, the
operator has just measured the vertical distance between the
visual rays projected by the cross hairs at the position occupied
by the rod.   The bottom hair, in figure 8, for example, cuts the
rod at a point, the distance of which below the point where the
middle hair would intersect the rod, were the rod long enough,
has just been determined.   Similarly, the top hair in figure 9
intersects the rod at a known distance above the middle hair.
Hence, if any of the three hairs rests on the rod when the tele-
scope is level, the vertical difference between instrument and rod
may be measured directly.

Examples are illustrated in figures 8 and 9.   In the former,
the horizontal distance has been read as 1050 feet and with level
telescope the bottom hair intersects the rod 9.6 feet above its
base, which is therefore 14.85 feet below the elevation of the
instrument.   In the latter, the horizontal distance has been
determined as 1960 feet and with level telescope the top hair
intersects the rod 1.8 feet above its base, which is therefore 8
feet above the alidade.

In practice it is only necessary to record the horizontal dis-
tance and the rod intersection, noting which hair intersects the

rod, with level sight. The vertical distance can be determined later by addition or subtraction.

2. *The step method.*[12]   The same principle may be extended to cover a much larger range of circumstances.   Suppose the rod is so far below the elevation of the alidade that with level sight all three hairs project rays slightly above the top of the rod.   Note where the middle hair intersects any fixed object in the field—a point on a nearby tree, or a certain rock on the distant hill-side. Turn down the instrument until the top hair intersects the
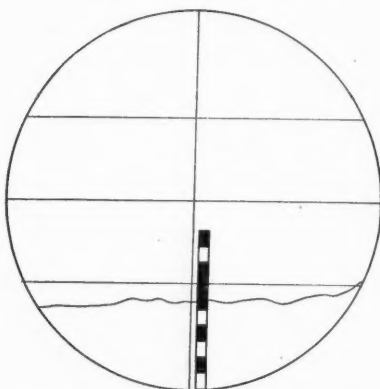
FIG. 8. STADIA ROD IN FIELD OF VIEW WITH LEVEL TELESCOPE AT DISTANCE OF 1050 FEET

The base of the 13 foot rod is 14.8 feet below the elevation of the alidade.
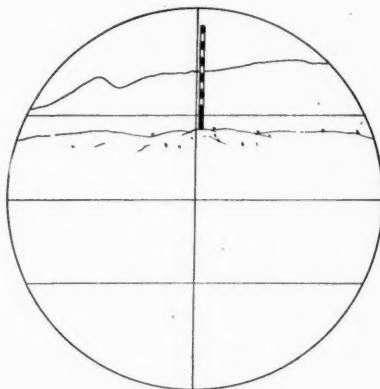
FIG. 9. STADIA ROD IN FIELD OF VIEW WITH LEVEL TELESCOPE AT DISTANCE OF 1960 FEET

The base of the rod is 8.0 feet above the elevation of the alidade.

same object.   The bottom hair now appears to be 1/100 the horizontal distance, previously determined by the stadia intercept on the rod, below the point where the middle hair had formerly been.   If the bottom hair now cuts the rod, read its inter-

[12] Douglas, E. M., The stadia and stadia surveying.   Engineering News, vol. 63, pp. 483–484, 1910.   Meyer, A. F., The "interval" method of determining elevations in stadia surveys.   Engineering News, vol. 64, pp. 231–232, 1910. Edgerton, H. H., Jr., Modern methods of economical railway location. Engineering and Contracting, vol. 41, pp. 229–232, 1914.

section and add that figure to 1/100 the horizontal distance to get the V. D. (vertical difference in elevation), which in this case, would be negative. If the bottom hair is still above the rod, note where it in turn intersects some fixed object in the field of vision and turn down the instrument until the top hair occupies its position. The bottom hair now appears to be 2/100 the horizontal distance below the point intersected by the middle hair with level sight. The process may be repeated, noting how many "steps" are used, until the bottom hair finally intersects the rod.

Obviously, the same method may be utilized for determining elevations of stations above the instrument by "stepping up" from the level sight until the top hair cuts the rod. Figure 10 illustrates the method. In recording observations it is only necessary to note the observed distance, the number of steps, the final rod intersection, and the sign of the V. D., plus for stations above and minus for stations below the instrument elevation. For example, a sight to a station 1760 feet distant, recorded as "+4 (steps) − 3.5", indicates that the base of the rod is (4 × 17.6) − 3.5, or 66.9 feet above the instrument. Or, a sight of 1320 feet with the V. D. recorded "− 3 (steps) − 12.9" indicates that the base of the rod is − (3 × 13.2) − 12.9, or − 52.5 feet in relation to the altitude of the telescope.

Attention should be directed again to the fact that the first "step" is in reality only a "half step" for by it one of the outer hairs is moved to the position occupied by the middle hair, whereas, each step, after the first, involves the movement of one outer hair to the position occupied by the other outer hair. This is compensated by the fact that the reading of the rod intersection after the final "step" is a reading of the position of an outer hair, not that of the middle hair. This makes the final "step" really a "step and a half" for the hair, the intersection of which is read, is a half intercept above or below the middle hair.

The "step" method when used by an experienced instrument man is very fast and fairly accurate. It is not, however, sufficiently accurate for important work, as there is wide margin of

error involved in the placing of one hair in the position previously occupied by another. Moreover, there is no simple way of correcting the error resulting from the inclination of sight to the rod when the intercept is read. The "step" method should
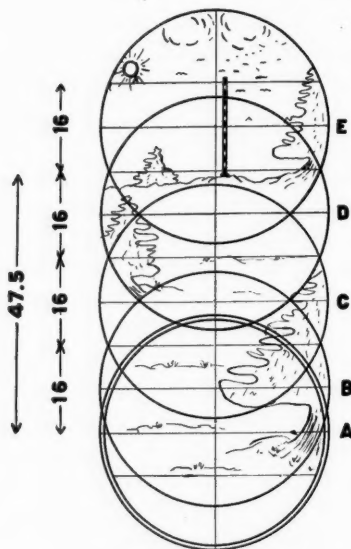

FIG. 10. THE STEP METHOD

Circle A encloses the field of view as observed through the level telescope. Circle B is the field after the telescope has been raised so that the bottom cross hair occupies the position occupied in A by the middle hair. C and D represent the second and third steps, in each of which the bottom cross hair rests in the position previously occupied by the top hair. In D, the third step, the top hair cuts the rod 0.5 feet above its base. The rod intercept, 16 feet, is indicated in E. The base of the rod is therefore $3 \times 16 - 0.5 = 47.5$ feet above the instrument.

never be used when more than 6 steps are necessary, nor to determine the elevation of a turning-point or set-up. It is well fitted to serve as a check upon the more accurate methods next described, when there is need for especial care to guard against error.

3. Vertical arc determinations. Other and more accurate methods of measuring the difference in elevation between two stations depend upon the determination of the vertical angle between the line of sight from one station to the other and the line of sight through the level telescope. The methods differ only in respect to the reading or computation of that angle; all are based upon the same mathematical principle. In figure 7, *FE* represents the vertical distance from the intersection of the middle hair on the rod, *AB*, to the level of the instrument at *G*. *CD* is drawn perpendicular to the line of sight, *GE*, the angle of inclination of which is represented by *m*.

By trigonometry

$$CD = AB \cos m$$

and

$$FE = GE \sin m.$$

But

$$GE = 100\, CD = 100\, AB \cos m;$$

therefore

$$FE = 100\, AB \sin m \cos m = 100\, AB \times \tfrac{1}{2} \sin 2m,$$

the formula upon which stadia tables are based.

The angle of inclination of the line of sight to the target may be read in degrees and minutes by means of the vertical arc. With loosened clamp the telescope is raised or lowered until the middle cross-hair rests *near* the selected target. The clamp is tightened and by means of the tangent screw the middle hair is accurately placed on the target. The point on the vertical arc opposite the zero of the vernier is read to the nearest minute and recorded. The telescope is then leveled, first loosening the clamp if desired, and the bubble in the striding level centered by adjustment of the tangent screw. The point on the vertical arc now opposite the vernier zero is read and recorded; the difference between the two readings is the desired vertical angle.

The graduations of the vertical arc differ on alidades of different manufacture, but one of the common graduations is indicated in figure 11 by the markings on the left half of the arc. The main scale of the arc is divided into degrees and half degrees.

By means of the vernier it may be read in minutes.   The vernier is an auxiliary scale on which there are 30 graduations occupying a space equal to that of 29 graduations on the main scale.   That is, each division on the vernier is just one-thirtieth smaller than a division on the main scale.   If, therefore, the zero line of the vernier is directly opposite a line on the main scale, no other line on the vernier scale will coincide with a division of the main scale except the thirtieth.   If, then, the arc be moved one minute (= one-thirtieth of one division) to the right, the first line on the left of the vernier zero will coincide with a line on the main scale; if the arc be moved 15 minutes to the right, the fifteenth line on the left of the vernier zero will coincide with a line on the main scale, etc.   On this principle the arc graduated only to half degrees may be ·read in minutes.   On an arc graduated from right to left, read the highest division to the right of the vernier zero line; this will be either an even degree or a degree plus 30 minutes.   Observe which line on the vernier coincides with a line on the main scale; add its value in minutes to the reading of the main scale.   For example: the vernier zero is between the 24° 30′ and 25° graduations of the main scale; line 16 on the vernier coincides with a division of the main scale; the arc reading is therefore 24° 46′.

A vertical angle of 1 minute subtends a chord of 0.3 feet at a distance of 1000 feet; hence it is imperative that no mistake be made in selecting the vernier division which coincides most closely with a line of the main scale.   Most surveyors make it a practice always to use a pocket magnifier in reading the vernier. It is also easier to detect offsets of the main scale and vernier division lines if one looks obliquely along the lines at an angle of 30 or 40 degrees with the face of the scale than it is when observing the vernier face from a direction perpendicular to it.   The most common of the serious errors which may involve the vernier reading is to overlook the $\frac{1}{2}$ degree division of the main scale and count it as an even degree; guard against that blunder by computing the position of the vernier zero twice for each angle.

Most alidades are equipped with adjustable vernier and with main scale so graduated that the vertical arc may be set to read

30° 00′ when the telescope is level. Among topographers it is customary, in reading vertical angles, first to level the instrument and set the vernier at 30° 00′, and second to turn the telescope down or up for the reading on the distant object. It is then necessary to record only one angle reading—that made after the cross-hair is set on the target; a reading less than 30° 00′ indicates an angle of elevation, one greater than 30° 00′ an angle of depression if the arc is graduated from right to left. This procedure is not recommended for petroleum geologists, however, because of inherent differences in the work of these two classes of alidade-users. In the topographer's party the lowest-paid man is ordinarily holding the rod on the station to which the sight is being taken. It is of little consequence whether he remains there four minutes or two. When he is moving on to the next station the topographer's time is occupied with sketching contours; he has no idle moments. In the petroleum geologist's party, the reverse is the case. The highest-paid man ordinarily holds the rod; the amount of work the party can do in a day is in inverse ratio to the length of time he is kept idle while the instrument man makes observations. While he is moving on to the next station, the selection of which will ordinarily require 10 to 20 minutes, the instrument man has nothing to do except compute his results—a task which if necessary may be done later in "the office." Moreover, the geologist's plane table is customarily lighter and smaller than that used by the topographer; it is seldom possible to get it in a precisely level attitude. Therefore it would be necessary to level the telescope and set the vernier after the geologist has occupied the fore sight station and while he is waiting for the observations to be made. The procedure of the instrument man should be planned explicitly to minimize the length of time the rodman is kept at a station. Just as much of instrument work as possible should be done after the rodman has been "waved on." With this in mind, the instrument man signals the rodman as soon as the cross hair is set on the selected mark on the rod; after the rodman has departed he reads and records the vernier, levels the telescope, reads and records the new position

of the vernier, wherever it happens to be, and determines the vertical angle by subtraction. He is then under no pressure of haste in reading the vertical arc and in centering the level bubble. To increased speed of geologic work is added thereby greater accuracy in instrumental observations. The record, then, includes two angle readings, one on the target and one with level telescope; the sign of the angle, plus for stations above and minus for those below the altitude of the table; and the observed inter-
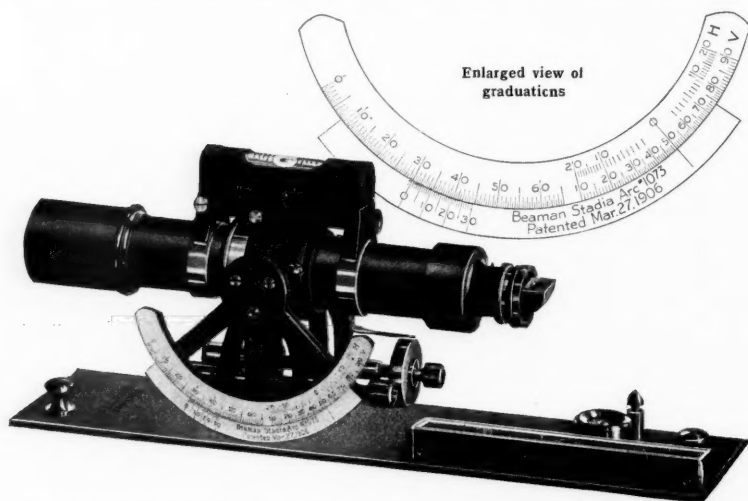

FIG. 11. EXPLORERS' ALIDADE, WITH VERTICAL ARC COMBINED WITH BEAMAN STADIA ARC

Courtesy of W. and L. E. Gurley, Troy, N. Y.

cept on the rod. From these data the vertical distance may be computed at leisure.

4. Beaman stadia arc. The reading of vertical angles may be avoided by the use of the Beaman stadia arc, illustrated in figure 11. This is a specially graduated vertical arc which may be attached to the vertical limb of a transit or telescopic alidade. It carries two scales, of which the one nearer the adjustable index is known as the multiple scale because it indicates mul-

tiples for obtaining differences in elevation. The zero point of this scale is marked 50 and its divisions are so spaced as to be proportional to one-half the sine of twice the angle through which the telescope moves.

To determine differences in elevation read the distance subtended on rod and express in feet (for example, 8.7 = 870 feet). Clamp telescope and level. Set index exactly at 50, by means of the tangent screw back of arc, and do not touch this tangent screw again.

Then, by means of the customary clamp and tangent movement, raise or lower telescope until there is brought exactly opposite the index such a graduation on the multiple scale as will throw the middle stadia wire somewhere on the rod, it does not matter where. The arc reading, minus 50, multiplied by the observed stadia distance gives the difference in elevation between the instrument and a known point on the rod—that is, the height on rod indicated by middle wire. Settings of both index and arc should be made carefully under reading glass.

Example: Suppose observed stadia distance is 6.3 (630 feet) and that telescope is so inclined that multiple scale reads 58, at which exact setting the middle wire on rod reads 7.2 (7.2 feet above base of rod) then multiple is $58 - 50 = + 8$, and computation for a fore sight would be

$$
\begin{array}{r}
6.3 \\
\times 8 \\
\hline
+50.4 \\
-7.2 \\
\hline
+43.2 \text{ feet} = \text{base of rod above H. I.}
\end{array}
$$

If middle wire were set on H. I. or top or other fixed point on rod and the arc were read by estimation (for example, 54.2) to obtain a multiple, the result would be approximate only; therefore this method is not to be used with this attachment.

If the half-wire interval is read and this reading is then doubled to get the stadia distance, it occasionally happens that no even multiple arc setting which will throw middle wire on rod can be found. In this case make arc setting that will throw the lower wire anywhere on rod; the middle wire will then be somewhere above the top of the rod. Then take multiple as read on arc, but compute position of middle

wire above base of rod by adding one-half the expressed stadia distance (in feet subtended) to the reading of the lower wire.

Example: If the half wires subtend 7.2 on rod, the distance would be $7.2 \times 2 = 14.4$ (1440 feet). If the lower wire cuts the rod 8.7 feet above its base, the computed middle wire reading would be $8.7 + 7.2 = 15.9$ feet above base of rod. Then compute as before.[13]

The advantages of the stadia arc are readily apparent. The use of stadia tables, slide rules, or diagrams is entirely obviated, nor is there any vernier to be read. The accuracy of results is identical with that obtained from formula or table computations; in fact differences in elevation may be read more closely than is possible where vertical angles are determined only to the nearest minute. Moreover the simplicity of the process eliminates many of the chances of error which are incidental to the use of other methods and gives final results in minimum time. The use of the arc is, however, limited to sights which involve the reading of the stadia rod, and for most "shots" it holds the rodman on the station longer than is necessary with certain other methods.

If it is desired to use the Beaman stadia arc principle with an instrument not regularly equipped for such work, the ordinary vernier arc may be used by reference to the following table, which is also of use in checking the action of the Beaman scale. It is computed from the formula:—vertical distance $= \frac{1}{2}$ sine of twice the vertical angle, and gives values by which the Beaman intervals can be translated into angular valuations and vice versa.

5. Stebinger gradienter drum. The accuracy of a sensitive bubble vial in the striding level is greater than that implied by the reading of the vertical angle only to even minutes. The fine adjustment tangent screw is so threaded[14] that a complete

[13] Topographic Instructions of the U. S. Geol. Survey, Washington, Gov. Printing Office, 1918, pp. 131–2.

[14] The intention of the makers commonly is to calculate the pitch of the screw and the length of the clamp arm so that one complete revolution of the screw head moves the line of sight 1 foot vertically at a horizontal distance of 100 feet, but this ratio may not be safely depended upon except as a broad approximation.

Table showing angular values of Beaman intervals*

NUMBER OF INTERVAL	ANGLE		DIFFERENCE IN MINUTES	NUMBER OF INTERVAL	ANGLE		DIFFERENCE IN MINUTES
	°	'			°	'	
0		00.00					
			34.38				36.16
1	0	34.38		16	9	19.89	
			34.39				36.42
2	1	08.77		17	9	56.31	
			34.42				36.70
3	1	43.19		18	10	33.01	
			34.47				37.00
4	2	17.66		19	11	10.01	
			34.52				37.32
5	2	52.18		20	11	47.33	
			34.59				37.71
6	3	26.76		21	12	25.04	
			34.68				38.08
7	4	01.44		22	13	03.12	
			34.77				38.49
8	4	36.21		23	13	41.61	
			34.88				38.95
9	5	11.09		24	14	20.56	
			35.02				39.44
10	5	46.11		25	15	00.00	
			35.16				39.97
11	6	21.27		26	15	39.97	
			35.33				40.54
12	6	56.60		27	16	20.51	
			35.50				41.16
13	7	32.10		28	17	01.67	
			35.71				41.85
14	8	07.81		29	17	43.52	
			35.92				42.58
15	8	43.73		30	18	26.10	

*Reproduced by permission from Metro Manual, Bausch and Lomb Optical Co., Rochester, N. Y., 1915, p. 114.

revolution deflects the telescope about 34 minutes, so that if the unit of measurement be 1/500 a revolution of that screw, the accuracy of reading vertical angles is greatly increased. This is especially important in determining the difference in elevation of a station two to eight miles distant as is frequently done in triangulation work. The Stebinger gradienter drum surround-

ing the tangent screw is graduated into 100 divisions, so broadly spaced that the drum may be read accurately by estimation to 0.2 division, and so quickly legible that there is marked saving of time and increased safeguard against error in observation when it is used in preference to the vertical arc.   It is in reality simply another method of reading the vertical angle, denoting the angle by an arbitrary unit instead of by degrees and minutes. The value of that unit in length of chord at known distances may be expressed in tables similar to those provided for computation from vertical arc readings.

In most instruments a clock-wise rotation of the Stebinger drum depresses the objective end of the telescope by pressing against a little stud fixed to the inside surface of the right hand standard.   A counter-clock-wise rotation permits a spiral spring to expand against the opposite side of the stud and thus to raise the objective end of the telescope.   Experience indicates that it is unsafe to trust the spring to act with uniform regularity and smoothness.   It is therefore necessary in using the Stebinger method always to read vertical distances in one direction— usually downward[15]—the direction in which the telescope is moved by clock-wise rotation of the drum.   If the station is higher than the telescope, the first reading is taken with the horizontal cross-hair cutting the target; the telescope is then turned down to the level position for the second reading.   If the station is lower than the instrument, the telescope is leveled for the first reading of the Stebinger drum and then turned down till the cross-hair cuts the target for the second reading.

The fine adjustment screw to which the Stebinger drum is attached is a tangent screw; that is, its motion is tangential to the arc described by the arm of the clamp of the telescope axis. Therefore, a revolution of the screw, when it is near one of its limits of motion will elevate or depress the telescope through an arc slightly different from that resulting from an equal turn of the screw when it is midway between its limits.   Therefore it is

[15] In some instruments the screw is fixed to the telescope standard and the stud is attached to the arm of the clamp of the telescope axis; when so attached the direction of movement to be used in reading the gradienter is upward.

necessary always to begin an angle reading with the tangent screw in approximately the same position as that from which the determination of the Stebinger factors was made. This position, generally about a quarter turn of the screw after it first "takes hold," should be indicated by a mark on the celluloid or steel index. After each reading the tangent screw should be withdrawn to that position, ready for the next reading.

In practice, then, the first reading is made with the Stebinger drum somewhere near the predetermined starting point and with the cross-hair on the distant object, if it is higher than the instrument or with the telescope level if the sight is a "down shot." The reading, a figure between 0 and 100, is recorded in the proper column of the note book. The telescope is then turned down by means of the tangent screw to position for the second reading. As the Stebinger drum revolves the total number of revolutions should be counted. The count may be verified by the graduations on the index bar if present and is set down at the left of the two digits which indicate the Stebinger division beneath the index. For instance, after completing 8 revolutions, the Stebinger drum is brought to rest at 67; the second reading is therefore recorded in the appropriate column as 867. With an alidade which "reads down," as is the more common arrangement, the smaller of the two Stebinger readings will be in the "Sight" column if the target is higher than the instrument, and in the "Level" column if lower than the instrument. The difference of the two readings expresses the size of the vertical angle in terms of Stebinger divisions. From the Stebinger tables prepared for the individual instrument the corresponding "Stebinger factor" is selected. This factor multiplied by the apparent distance gives the difference of elevation of target and plane table.

The preparation of the Stebinger tables is essentially the determination of the value of Stebinger units in terms of circular measure. Withdraw the micrometer screw to the position from which determinations of vertical angles will be started. Set the drum on an even division and read the vertical arc; turn the drum through 100 divisions and read the arc again. Turn

through 200, 300, etc., divisions, reading the arc at each hundred until the screw has reached the farther limit of its play. Usually 9 or 10 hundred divisions will suffice. Repeat the operation at least five times and take the average value in minutes for each hundred divisions. Determine the corresponding difference in elevation for each of these angles by interpolation of the regular stadia tables or from a table of natural sines by the formula: Difference of elevation = $\frac{1}{2}$ sine of twice the angle. The first value thus determined divided by 100 is the difference in elevation corresponding to each Stebinger division between 0 and 100. The second value minus the first and divided by 100 is the difference in elevation corresponding to each Stebinger division between 100 and 200. The third minus the second and divided by 100 is the value for Stebinger divisions between 200 and 300, etc. Carry the quotients in each case to the fifth decimal. With an adding machine set at the difference in elevation for one division between 0 and 100, print 100 additions for the factors corresponding to the first 100 Stebinger divisions. Then with the machine set at the difference in elevation per division between 100 and 200, print 100 additions for the factors corresponding to the second 100 Stebinger divisions. Complete the table in this manner, changing the addition figure after each 100 additions. Number the divisions, strike out the extra decimals beyond the third for the first 50 divisions and beyond the second thereafter, and typewrite into tabular form in parallel columns; the number of divisions in one column, the corresponding factors in another. Brief tables for correction because of curvature and refraction as well as for conversion of observed to horizontal distances should be added at the margin. The whole, if properly planned, will occupy a sheet about 5 × 7 inches in size when photographed to one-half reduction for field use.

A slight modification[16] of the above method will give a still more accurate series of factors. Read the vertical arc at each 50th division of the Stebinger drum instead of each 100th; deter-

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[16] Suggested by K. C. Heald of the U. S. Geological Survey.

mine the corresponding difference in elevation for each Stebinger unit as before; with the factors thus obtained plot a curve using the numbers of divisions as the abscissas and the values as the ordinates. From this curve the point will be readily apparent at which the micrometer screw begins to work with reasonable uniformity; begin constructing the table to be used at that point. From the curve determine the points where the factors for two successive divisions differ by 0.00005 and compute the factors for the number of divisions represented by each of these points; interpolate between the values thus obtained to complete the table.

The table of Stebinger factors should be checked every few weeks by comparing a half dozen Stebinger readings, made at haphazard intervals well distributed throughout the range of the micrometer screw, with the corresponding readings of the vertical arc. The Stebinger factor should be identical, on the average, with the vertical distance corresponding to the arc reading.

In reading the Stebinger drum the observation should be made from directly above the celluloid or steel index so as to project the index line vertically downward to the drum. Ordinarily, a reading to the nearest Stebinger division is sufficiently close, but for low angles and long "shots" it is better to estimate half divisions, and for the nearly horizontal two-to-five mile "shots" of triangulation it is frequently worth while to estimate to tenths of a division. For these long sights, the distance of which is determined by scaling off the space on the map, there is a theoretical error in using tables based on the formula involving one-half the sine of twice the angle, but there is practically no discrepancy here for the difference between the sine of a small angle and one half the sine of twice the angle is negligible.

CURVATURE AND REFRACTION.

No matter what method of determining vertical distances is used, a correction for curvature and refraction must be applied to all "shots" of a mile or more in length. The level datum to

which all elevations are referred is a surface having the curvature of the Earth; the line of sight through the telescope in a level position is tangential to this curved surface; therefore distant objects appear to be higher above the datum plane than is actually the case. In the greatly exaggerated figure 12, for example, the rod reading is increased from C to A. The result of curvature can be determined with reasonable accuracy. It varies directly as the square of the distance and may be computed by the formula: Curvature $= 0.667 \times D^2$, where D is the distance in miles.
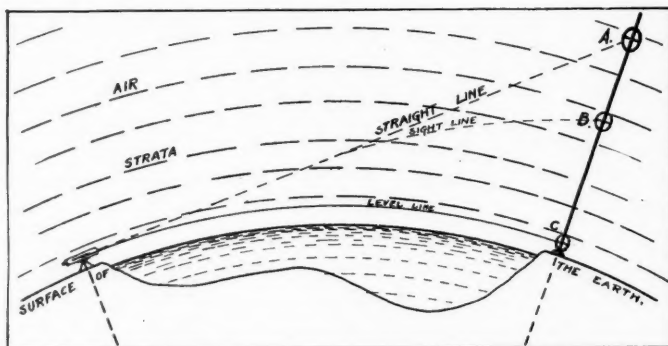
FIG. 12. DIAGRAM, GREATLY EXAGGERATED

Showing influence of curvature and refraction upon observations for determining differences in elevation between two points.

Refraction, on the other hand, has the opposite effect. When light rays pass obliquely from one air stratum to another of different density they are bent or refracted from their original position. In figure 12, the light from the target at B, passing into air strata of increasing density as it travels to the alidade at the left, is bent downward and enters the telescope as though it had come by a straight line from A. Thus, the effect of normal atmospheric refraction is to make distant objects appear higher than they really are. It, therefore, tends to decrease the curvature correction, as shown in the figure. The amount of refraction depends upon the density of the air and is, therefore, quite

variable.   It is much greater near the ground than 3 feet above
it, and generally greater at midday than early in the morning or
late in the afternoon.[17]   The empirical valuation ordinarily
placed upon the effects of refraction gives the combined for-
mula: Curvature plus refraction = $0.57135 \times D^2$.

A table showing corrections based on this formula may be
found in the ordinary stadia tables.   The correction amounts to
only 0.1 foot for distances of 2200 feet, 0.2 foot for 3125 feet
and 0.5 foot for 4940 but increases rapidly to more than 5 feet at
3 miles and 20 feet at 6 miles.   It may safely be disregarded for
the great majority of rod "shots," which will of course be less
than 3000 feet long.

The correction is always a minus quantity and should be
added algebraically after the proper sign has been placed in
front of the vertical distance as instrumentally determined.   It
will thus increase the vertical distance for angles of depression
and decrease it for angles of elevation on all fore-sights.   Occa-
sionally, for nearly level sights the correction to be applied for
curvature and refraction will be greater than the observed dif-
ference in elevation, and the sign of the vertical distance may
than be changed.   No confusion will arise, if the rule stated in
the first sentence of this paragraph be rigidly observed.

ADJUSTMENT OF THE ALIDADE

The most important adjustments of the miniature or ex-
plorer's alidade, which require attention in the field, are those
for collimation and of the striding level.   All other adjustments
are reasonably permanent as made in the factory.   It is, how-
ever, well for the instrument man to be able to detect, and if
possible correct, faulty workmanship or damage from mistreat-
ment or accident.

Collimation.   The line of sight through the telescope is deter-
mined by the intersection of the cross-hairs, whatever their
position in the tube, and the nodal point in the objective lens.

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[17] Obviously, the refraction to which reference is here made is not that of the
direct rays of light from sun or stars.   The refraction for which correction must
be made in determining sun azimuth is least between 9 a.m. and 3 p.m.

This line is correctly collimated when it coincides with the optical axis of the objective. That is, the intersection of the cross-hairs should remain stationary in the field of vision when the telescope is rotated on its horizontal axis. The telescope is mounted between 180-degree stops in the axis-sleeve for this purpose.

Sight some distant fixed object of small size and center the cross-hair exactly upon it. The telescope need not be horizontal. Rotate the tube carefully half way round and twist the prismatic eye-piece back into position. Note whether the cross-hairs are still centered upon the object. If not, correct half the discrepancy by means of the diaphragm adjusting studs, which may or may not be concealed beneath a ferrule which forms a guard against accident or tampering. In figure 13, let the original position of the cross-hairs be represented by the lines passing through the point A, their position after rotation of the telescope by the lines passing through the point B and their collimated position by the lines passing through the center of the circle. Move the vertical hair to left or right by turning both lateral studs in the same direction, first slightly loosening the one, then tightening the other. If the alidade is of the erecting type with field reversed from right to left, as is commonly the case, loosen the screw *away from which* the *vertical* hair must apparently be moved, and tighten the opposite screw. Move the horizontal hair up or down by turning top and bottom studs in the same direction, first slightly loosening the one and then tightening the other. If the eyepiece is of the erecting type, loosen the screw *towards which* the *horizontal* cross-hairs must apparently be moved and tighten the opposite screw. Having corrected half the discrepancy in this way, shift the alidade until the cross-hairs are again centered upon the distant object, and

Fig. 13. Diagram Illustrating the Adjustment for Collimation

rotate the telescope as before. The line of sight should now remain fixed upon the distant point; if it does not do so, correct half the apparent error as before. Repeat until the hairs are properly centered.

The test for collimation should be frequently made. No important triangulations should be begun until one is certain that the cross-hairs are properly located. Should the instrument be subjected to any unusual jar, it must be collimated before it is again used. In the normal routine of field work the position of the cross-hairs should be examined at least once each week.

Striding level. The line of sight when correctly collimated should be in absolute parallelism to the bubble axis, which is a line tangential to the curved surface of the striding level vial at the center of its scale. The two "red metal" collars which support the striding level are trued in the factory to the axis of rotation defined by the axis-sleeve within which the telescope rotates. There is very little chance for wear in the sleeve and the collars themselves are subject to little or no wear, so that this adjustment is a fairly permanent one. The customary test of parallelism is therefore simple and rapid. Level the telescope by the striding level, then turn the level end for end on the collars. If the bubble does not come to rest in the same position as before, correct one half of the indicated error with the tangent screw and the other half in the striding level by turning the set screw in the crotch of one of the wyes with a screw driver. This will secure parallelism between the bubble axis and the contact points on the collars, but does not guarantee parallelism with the line of sight although that has supposedly been provided for by the maker of the instrument. The reliable test is that of the peg-method described in most surveying manuals.[18]

Stadia constant. In alidades of the type customarily used by geologists, the distance between the stadia hairs is fixed in manufacture and may not be adjusted in the field. Occasional test should be made to ensure a close approximation to the fixed

[18] Tracy, Plane Surveying. New York, 1907, pp. 597–600. Metro Manual, Bausch and Lomb Optical Company, Rochester, N. Y., 1915, pp. 19–20

ratio of 1:100 between observed intercept on the rod and distance from alidade to rod. Read the rod intercept at accurately measured distances between 100 and 1000 feet from the instrument. If the stadia hairs do not give intercepts sufficiently accurate for the work in hand, the discrepancy may be remedied either by preparing a specially graduated rod adapted for the particular alidade or by computing a constant by which observed distances must be multiplied in order to give true distances.

Bullseye level. The inner surface of the circular bubble by means of which the alidade base is made approximately to coincide with the horizon is that of a sphere of long radius. The alidade base should be parallel to a plane which is tangential to this sphere at the point defined by the bubble indices. Once adjusted in the factory it is rarely necessary to rectify the bubble to keep this parallelism within the rather broad limits required for plane table work, but in case of this necessity place the alidade upon a plane surface which is known to be level in all directions and tighten the screw toward which the bubble seems to creep.

Telescope axis. In order that the vertical cross-hair shall travel in a vertical plane, the telescope axis must be adjusted to horizontality. The requirements for plane table work are sufficiently met by the plumb line test. Carefully level the plane table and place the alidade along a ruled mark. Hang a plumb line in the field of view and revolve the table to check against it. If the vertical hair deviates to the right for instance, reverse the alidade along the guide line and test on another plumb line swung in the new field of view. If in this case the vertical hair deviates an equal amount to the left, the test will show that while the plane table is not horizontal in the direction of the telescope axis, the axis itself is correct.

Adjustment of the horizontal axis, should this ever become necessary, cannot be made in the field. The factory adjustment is considered to be so permanent that an adjusting block is not provided on alidades. Moreover, it would be difficult to fit such a contrivance, for the vertical arc is on one extension of the horizontal axis and the vertical clamp is on the other.

Fiducial edge.   While it is not essential for the fiducial edge to be more than approximately parallel with the line of sight, it is important that this edge be straight.   Draw a line against the straight edge and turn the alidade end for end.   If the straight edge coincides perfectly with the test line, the requirements are satisfied.

CARE OF THE ALIDADE

Like all instruments of precision the alidade must be handled with extreme care.   Its metal parts are composed almost exclusively of brass, bronze, and "red metal," materials which are not notably resistant to abrasion.   Precautions should constantly be taken, therefore, to keep the bearings free from gritty particles.   The instrument, for example, should never be placed on the ground or laid on a rock pile.   If for any reason it must be removed from the plane table, return it to its leather case and close the case tightly before depositing it anywhere.   The bottom must be kept clean.   The instrument in its case should at all times be protected against jar and shock.   The habit of dropping the alidade to the floor of an automobile to be shaken around in transit with hammers, specimens, tire tools and other impedimenta is indefensible.   Treat it with at least as much consideration as one gives to lunch-kit and thermos bottles.

Once or twice a month, bearings, clamps and screws should be wiped clean with a cloth dampened in a light oil such as "3-in-1."   The springs which play against the bearing studs on the opposite sides from the vernier and tangent screws should be removed from their housings, wiped clean, stretched a little and replaced.

If the Stebinger drum is used in determining the elevations, the tangent screw must be treated with special care.   Experience indicates that very trivial and unobtrusive things may change the relation of the screw to the arc sufficiently to make a Stebinger table no longer applicable and necessitate the construction of a new one.   If possible, the gradienter screw should be entirely withdrawn every week or two and wiped absolutely clean with the oily cloth.   The bearing plate stud against which the point

of the micrometer screw pushes must be kept securely tightened. Should it become loose very erratic readings will result. The surface of this plate will gradually wear at the point where the micrometer screw bears against it until a distinct socket is made. Ultimately this becomes so pronounced that not only does it throw out the relation of the straight line push of the screw to the circular movement of the arc, but the point of the screw will not hit exactly the same spot on successive readings, and as a result three or four readings from the same station to the same object will fail to check. When that happens, the bearing plate should be surfaced with a file and a new gradienter table constructed.

The compass needle should always be raised from its pivot and clamped immediately after it has been used. "Protect the pivot in every way possible, for unless the pivot is sharp and perfect the needle may be sluggish and unreliable." Place the alidade as nearly as possible in the magnetic meridian before releasing the needle, and thus avoid the blow to the needle resulting from sudden contact with the compass box. The danger of destroying the polarity of the needle is another reason for guarding against reckless treatment of the alidade as a whole. When working in the rain, the compass box is the most vulnerable part of the instrument. Unless the glass cover is securely sealed all around, moisture will penetrate the box and put the needle out of commission by causing it to adhere to the inside of the glass. If this occurs, the box must be opened, the needle removed, and all parts thoroughly dried before proceeding with the work.

THE IMPORTANCE OF DRAINAGE AREA IN ESTIMATING THE POSSIBILITIES OF PETROLEUM PRODUCTION FROM AN ANTICLINAL STRUCTURE

KIRTLEY F. MATHER AND MAURICE G. MEHL

So fully is the general dependence of commercial accumulations of petroleum on rock structure accepted among the oil fraternity that the average report setting forth the possibilities of oil and gas production properly centers about the structure of the region concerned. Experience has indicated that accumulations of petroleum usually coincide with certain variations in the attitude of the reservoir rocks; mobility of liquid and gaseous hydrocarbons in tilted porous beds has been recognized to the extent that these structures are looked upon as entrapping "basins" or checks to the upward movement of hydrocarbons along the inclined strata. Attention, however, is usually focused on the nature of the accumulating structure or trap rather than on the nature of the area from which petroleum or gas could have been gathered. In the more common descriptions of a favorable structure, concise statements are made concerning its effectiveness as a trap as indicated by the amount of closure and the size of the area beneath which accumulations of oil or gas should occur; too often nothing is stated concerning the possible feeding ground which may have served as the source from which the oil or gas must come. Account is seldom taken of the fact that a large and effective accumulating structure may be so situated that it could have drawn an accumulation of petroleum from only a very small area; or, as we are here using the term, that the "drainage area" may be of such slight extent as to be insufficient to supply all the oil or gas which could be retained in the structural trap.

A map showing geologic structure by means of contour lines should therefore convey two items of valuable information to the

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man interested in the oil and gas resources of the region represented: (1) the location and extent of the areas beneath which oil and gas migrating up the dip of the reservoir rocks would be trapped; (2) the size of the area from which the mobile hydrocarbons might be expected to move toward this trap. The first of these is important in determining the location of drill holes; the second is an equally important factor in determining the volume of possible production from the favorable structure.

To those uninitiated into the mysteries of contour lines—and many such must constantly be dealt with in the petroleum industry—neither of these facts is apparent from the ordinary structure contour map. If the structure of the region be at all complicated, even the connoisseur must spend much time in a careful analysis of the contour lines before he can visualize the structure in all its details and grasp adequately the information thereby set forth. It has been found helpful in the interpretation of structure contours to draft an auxiliary map so planned as immediately to focus the attention upon these two facts undistracted by a maze of lines.

To illustrate the method and the result, there is presented herewith a structure contour map (plate XIX) of the four townships in the southwestern corner of the Pawhuska Quadrangle, Osage County, Oklahoma. The contour lines, redrawn from the township plats prepared by Heald, Winchester, Bowen, Condit, Emery, Clark and Mather,[1] represent a region of complicated structure comprising 31 anticlines and domes of sufficient individuality to be given distinctive names. Accompanying this contour map is an oversheet reproduced from a map prepared by N. L. Thomas, a member of our class in petroleum geology, delineating the area of each inverted basin and drainage tract. The space embraced within the lowest closed contour line on each anticlinal fold is diagonally ruled; the direction of migration of oil or gas in the reservoir rock is indicated by arrows; the feeding ground from which the hydrocarbons, accumulated on or

[1] Structure and oil and gas resources of the Osage Reservation, Oklahoma, Twps. 24 and 25 N., Rs. 8 and 9 E., U. S. Geol. Survey, Bull. 686, parts E, M and P, 1918–1919.

near the crest of each fold, may have been drawn is enclosed by
a sinuous line.

A merely desultory glance at the oversheet is sufficient to
enable one to grasp the import of the structure of the region so
far as its influence upon the accumulation of oil and gas is con-
cerned.   If we assume that a suitably porous reservoir stratum
is continuous beneath the surface of the entire region, that
hydrocarbons were at one time disseminated uniformly through-
out that stratum, and that they have subsequently moved up
the dip in obedience to gravitational sorting, we may conclude
that oil and gas will be concentrated in and near the shaded
tracts in amounts proportional to the size of the feeding grounds
or drainage areas.

Such a map obviously fails to present a complete picture of
the geologic structure of the region.   Where the rocks are faulted,
as they are in the area chosen for illustrative purposes, the struc-
tural drainage areas may be outlined only after making certain
unsupported assumptions as to the effect of faults upon the
movement of the hydrocarbons.   Here, for example, it was as-
sumed that faults whose maximum throw at the earth's surface
was less than 30 feet would not have prevented the up-dip
migration of oil or gas, while a fault with a throw of 50 to 70
feet—such as the one which slices the Ducotey anticline in
15–25–9—is believed to have effectually halted such migration.
Again, change of dip angle without any actual reversal of dip
direction or closure of contour lines may be all that is needed
to trap the migrant hydrocarbons; but it is impossible to state
in advance how much flattening of the beds is necessary to permit
a structural terrace to localize an oil or gas accumulation.   In
the illustrative case, it was decided to neglect all changes of
dip angle and consider as traps only true domes or doubly plung-
ing anticlines.   The drainage outline map must therefore be
used only in connection with the contour map on which it is
based; it is to serve as an aid to the ready interpretation of the
structure contours, not as an independent entity.

Possibly the greatest value of such a map to the petroleum
geologist is that it brings into merited prominence the factor of

drainage area. In our illustration, for example, the Wheeler dome near the center of 24–8 has about the same area within the lowest closed contour line as has the northeastern bump on the Wooster anticline in 27–25–9; the latter has 50 feet of closure, the former only 30, and hence the latter would be considered by many as a more valuable structure; but the oversheet draws attention to the fact that the drainage area contributory to the Wheeler dome is more than twice that which may have fed this portion of the Wooster anticline, and hence, other things being equal, the Wheeler dome should contain more than twice as much oil.

Outlining the possible gathering ground for each anticlinal fold, as on the accompanying plate, serves also to depict clearly certain of the peculiarities of distribution of producing wells in the Osage Reservation. In general, it is noted that the folds are so closely crowded that the drainage areas are all very small. In certain parts of the Reservation good production is obtained from pools so situated that none of the oil which they contain could have come from a greater distance than $1\frac{1}{2}$ miles. On the average, oil beneath Osage County has probably migrated only 2 or 3 miles from its point of entrance into the reservoir stratum to its resting place in an oil pool. Few accumulations are so situated as to have drawn oil or gas from points more remote than 4 miles.

Again, the asymetrical situation of the effective trap, almost invariably much nearer the eastern than the western margin of the drainage area, is forcibly presented. Experience indicates that production extends much farther down the longer flanks of the anticlinal folds than the shorter. Where the east flank is less than a mile long, little oil is found east of the crest of the fold; the area from which that portion of the anticline may have been supplied was insufficient to permit a commercial accumulation. In general, the amount of production from the various parts of an anticlinal fold seems to depend largely upon the length of the slope from the margin of the drainage area.
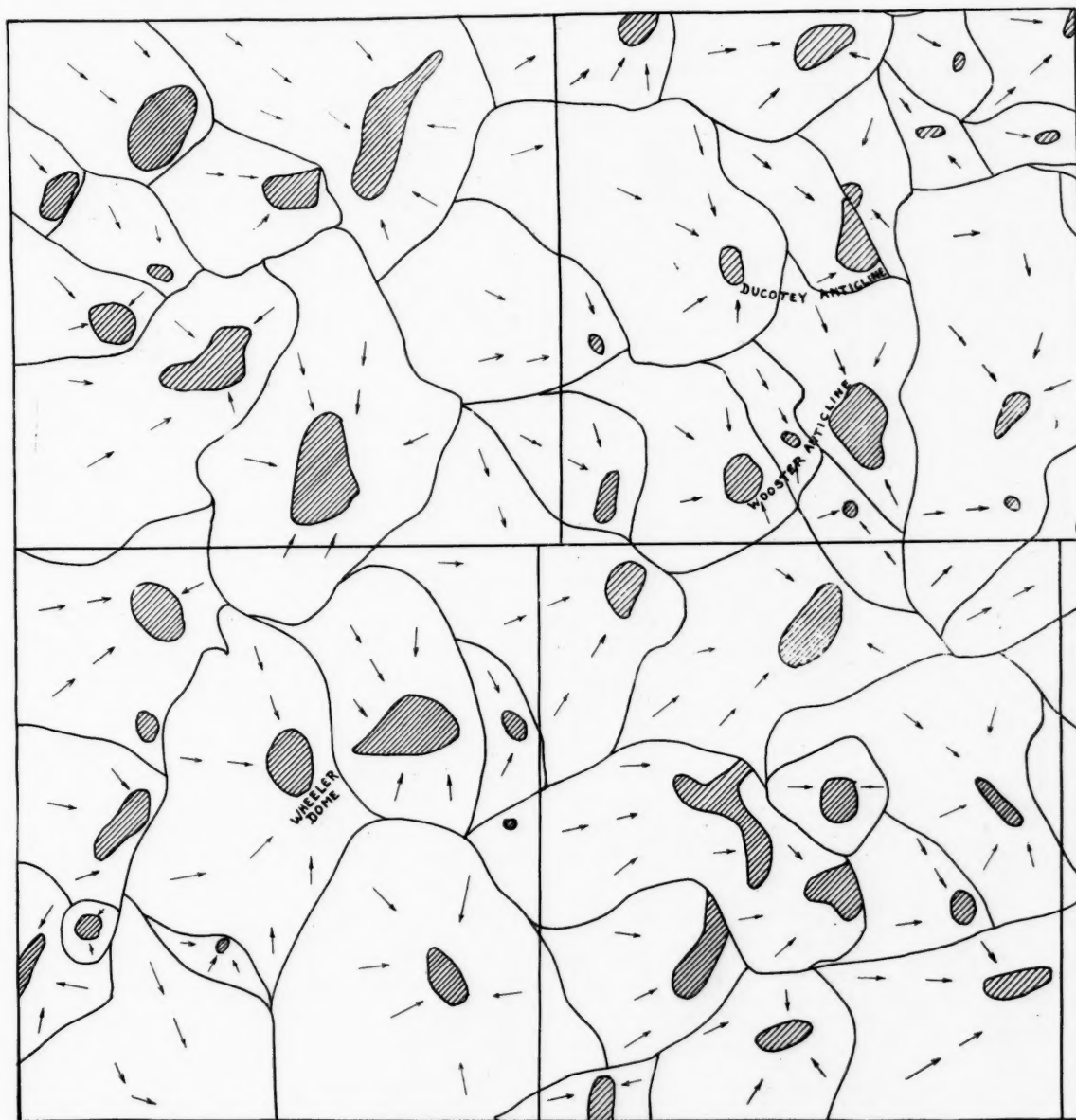
Map showing structural drainage areas in southwestern portion of Pawhuska quadrangle, Oklahoma. Shaded areas are inverted traps for oil and gas within closed contours; arrows indicate direction of migration of oil and gas

PLATE XIX
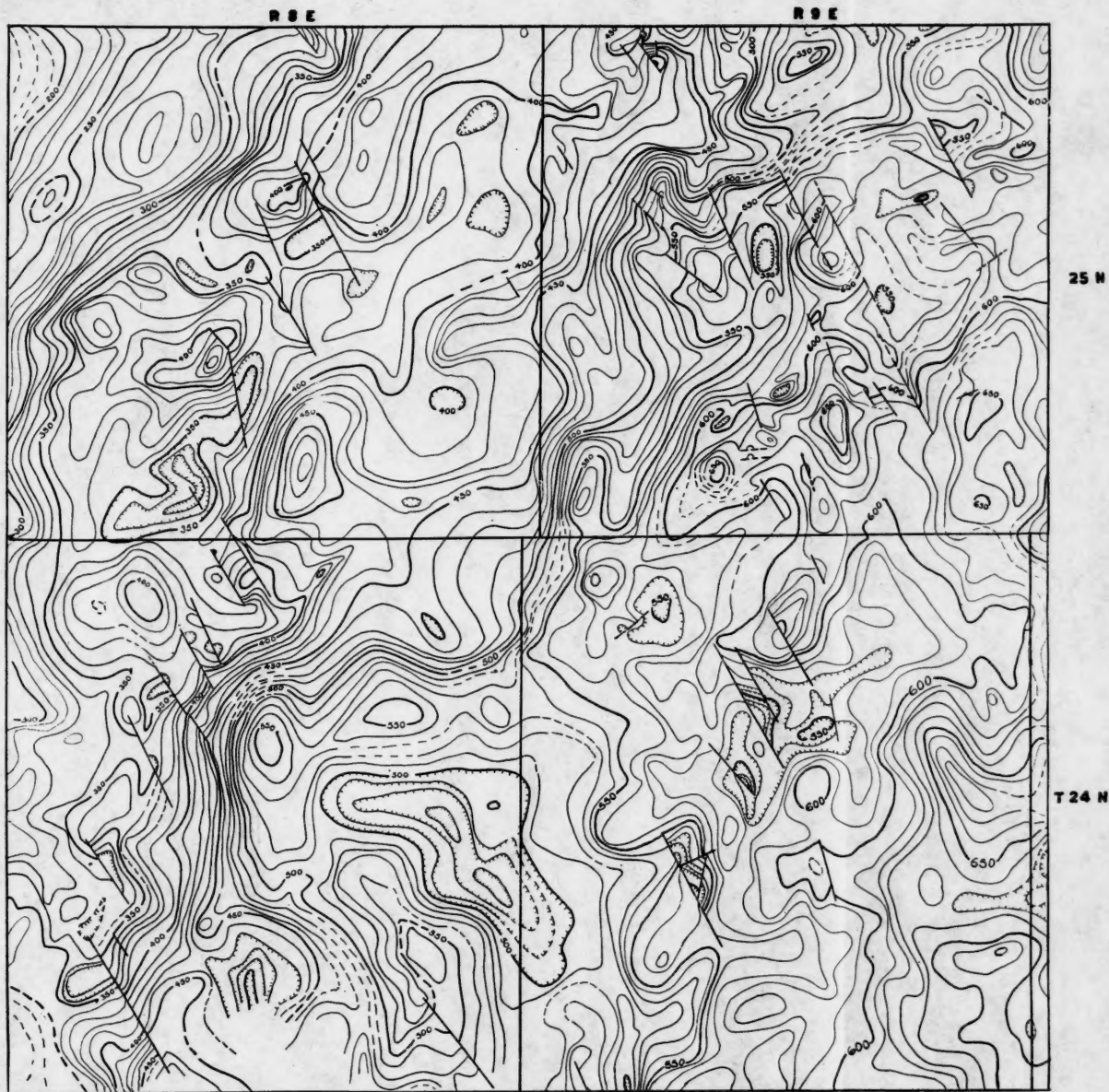
Map showing geologic structure of southwestern portion of Pawhuska quadrangle, Oklahoma. Contour interval, 10 feet; scale, 1:114,500. Redrawn from Plates VII, XXIV, XXV, and XXXII, Bull. 686, U. S. Geol. Survey, 1918–1919